BUILDING CHAN CHAN: THE APPLICATION OF CONSTRUCTION PROJECT MANAGEMENT TO THE ANALYSIS OF ANCIENT ARCHITECTURE

By

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For my wife Becki, whose love, understanding, support, and never-ending patience allowed me the opportunity to achieve my goal, and my parents, who taught me the value of hard work and self-reliance.

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS iv

LIST OF TABLES vii

LIST OF FIGURES ix

ABSTRACT xiii

CHAPTERS

1 INTRODUCTION 1

Problem Statement 1
Summary of Methodology 2
Historical and Theoretical Background 5
Methodology and Data Collection 16
Significance 22

2 PRINCIPLES OF CONSTRUCTION PROJECT MANAGEMENT 24

Introduction 24
Scope of Work 26
Estimating 29
Scheduling 52
Advanced Scheduling Techniques 61
Summary 72

3 CIUDADELA RIVERO 74

Introduction 74
Scope of Work 89
Estimating 91
Scheduling 115
Discussion and Conclusions 131

4 CONCLUSIONS 142

Significance 142
Hypothesis Testing 143
Conclusions 144
Applicability to Archaeological Research 146
Future Research 146

APPENDICES

A WBS - ORIGINAL CONFIGURATION 149

B WBS - MASSIVE ADOBE WALL ADDITION 153

C DETAILED ESTIMATE - ORIGINAL CONFIGURATION 156

D DETAILED ESTIMATE - MASSIVE ADOBE WALL ADDITION 172

E SCHEDULE DATA - ORIGINAL CONFIGURATION 180

F SCHEDULE DATA - MASSIVE ADOBE WALL ADDITION 195

G SCHEDULE OF ORIGINAL CONFIGURATION 202

H SCHEDULE OF ADOBE WALL ADDITION 214

LIST OF REFERENCES 219

BIOGRAPHICAL SKETCH 225

LIST OF TABLES

Table Page

2-1: Quantity survey of storeroom....31

2-2: Productivity - Manufacturing adobes....37

2-3: Productivity - Transporting adobes....39

2-4: Productivity - Adobe installation....43

2-5: Productivity - Mud Plaster....45

2-6: Productivity - Clay flooring - 5 cm....45

2-7: Productivity - Procuring cana brava - 3-cm diameter....47

2-8: Productivity - Transporting cana brava....48

2-9: Productivity - Procure and transport cana brava 1000 meters....48

2-10: Productivity - Procure and transport cana de guayaquil 1000 meters....48

2-11: Productivity - Fabricate roof panels....49

2-12: Productivity - Erect roof panels....49

2-13: Project estimate....51

2-14: Revised project estimate....56

2-15: Project estimate with probabilistic data....69

3-1: Summary of quantity survey....92

3-2: Productivity - Excavation....95

3-3: Productivity - Tapia construction 0-3 meters....100

3-4: Productivity - Tapia construction over 3 meters....101

3-5: Productivity - Adobe construction over 3 meters..105

3-6: Productivity - Plastering over 3 meters..107

3-7: Productivity - Harvesting and transporting algorrobo...................................108

3-8: Productivity - Recap of unit rates to estimate Ciudadela Rivero.......................109

3-9: Summary estimate for the original configuration...111

3-10: Summary estimate for the adobe wall addition...114

3-11: Estimated labor requirements and construction time of Gran Chimu...............138

3-12: Estimated labor requirements and construction time of four compounds...........140

LIST OF FIGURES

Figure Page

1-1: General location of Chan Chan......6

1-2: Layout of major compounds......7

1-3: Architecture at Chan Chan......10

1-4: Existing configuration of Ciudadela Rivero......18

2-1: Storeroom plan......27

2-2: Detail of storeroom roof construction......28

2-3: Work Breakdown Structure for storeroom......29

2-4: Informant making adobes in the Moche Valley......36

2-5: Stacked adobes ready for use......36

2-6: Runner-header bond in massive wall at Ciudadela Tschudi......41

2-7: Adobe wall building sequence......42

2-8: Cana brava......46

2-9: Cana de guayaquil......46

2-10: Basic logic diagram for storeroom......53

2-11: Logic diagram - consolidating the storeroom logic......54

2-12: Logic Diagram - simplified storeroom logic......55

2-13: Time-scaled logic diagram, early schedule......58

2-14: Resource distribution showing number of workers required per day......59

2-15: Labor distribution in hours per day......60

2-16: Simple resource constrained schedule....62

2-17: Revised resource constrained schedule....62

2-18: Complex logical relationships....63

2-19: Schedule using complex logic....64

2-20: Comparison of task specialization vs. work parties....67

2-21: Triangular distribution....69

2-22: Cost probability graph....70

2-23: Duration probability graph - task specialization model....71

2-24: Duration probability graph - work party model....72

3-1:Existing configuration of Ciudadela Rivero....76

3-2: North entrance looking through the massive adobe walls into the compound....77

3-3: Corridor between north adobe wall and tapia walls....77

3-4: View of gap in north tapia wall....78

3-5: View of proposed original configuration....78

3-6: Ramp and main platform of north sector entry court....80

3-7: View of north sector entry court in virtual model....80

3-8: Storeroom complex behind west forecourt....81

3-9: View of storeroom complex in virtual model....81

3-10: Typical ruins of an audiencia....82

3-11: Hypothetical view of audiencia....82

3-12: Walk-in well in central sector....83

3-13: View looking south across burial forecourt to burial mound....84

3-14: Hypothetical view of burial mound and forecourt in virtual model....84

3-15: Details of north sector....85

3-16: Typical narrow corridor in north sector....86

3-17: Central dividing wall connection between north and central sector....................87

3-18: Details of central sector and conchone....................88

3-19: Work Breakdown Structure for original construction episode....................90

3-20: Work Breakdown Structure for remodeling....................91

3-21: Estimated excavation quantities....................94

3-22: Cobble foundation of tapia walls....................98

3-23: Tapia blocks in east wall....................98

3-24: Close-up of tapia block....................99

3-25: Cross section of tapia wall in north sector....................99

3-26: Tapia wall construction....................100

3-27: Corner and rack-back leads....................102

3-28: Massive adobe wall showing alignment poles....................102

3-29: Vertical taper controls as proposed in the Chan Chan Museum, Trujillo, Peru...103

3-30: Speed leads on massive adobe wall....................104

3-31: Speed leads in use at the Convento in Espanola, New Mexico....................105

3-32: Cana scaffolding....................106

3-33: Use of cana scaffolding to plaster high walls....................107

3-34: Distribution of labor hours by work type for the original configuration....................112

3-35: Cost probability graph for the original configuration....................112

3-36: Distribution of labor hours by work type for the adobe wall addition....................114

3-37: Cost probability graph for adobe wall addition....................115

3-38: The effects of overtime on productivity....................117

3-39: Site layout surrounding Ciudadela Rivero. (Moseley 1994)....................118

3-40: Construction work flow....................121

3-41: Schedule with unlimited resources for original configuration....................123

3-42: Comparison of logic between task specialization and work parties....................124

3-43: Schedule using task specialization method for the original configuration...........125

3-44: Schedule using work party method for the original configuration...................126

3-45: Comparison of the three schedules for the original configuration...................127

3-46: Duration probability graph for unlimited resources....................................128

3-47: Duration probability graph for task specialization.....................................128

3-48: Duration probability graph for work parties..129

3-49: Comparison of labor distributions for the original configuration using the 95% probability project duration...129

3-50: Schedule for adobe wall addition..131

3-51: Duration probability graph for adobe wall addition....................................132

4-1: Schedule showing results of 48-hour workweek..146

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By

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Chairman: Dr. Brisbane H. Brown, Jr.
Major Department: M.E. Rinker Sr. School of Building Construction

This study demonstrates the relevance and establishes a methodology for the application of contemporary construction project management systems to ancient architecture for the testing of archaeological hypotheses concerning scale of construction, organization of labor, and complexity of social organization.

By employing industry standard planning, estimating, and scheduling tools, the labor requirements and construction times are calculated for the case study of the monumental adobe architecture of Ciudadela Rivero, at the site of Chan Chan, Peru, built by the Chimu around AD 1400. While the case study specifically concerns the adobe construction of the north coast of Peru, the methods are portable to other ancient architecture in any geographic region. Included in this research is the study of ancient adobe construction methods, as well as the development of productivity rates, project estimates, construction schedules, and a 3-D computerized model of Ciudadela Rivero.

The labor investment in ancient monumental structures is often an important factor in hypotheses concerning a society's size, organization, and complexity. Prior methods of quantifying labor expenditures were limited to simply designed structures with minimal numbers of tasks. Due to the lack of practical analytical methods, complex architecture was often described subjectively offering little quantitative value, resulting in inferences that could be misleading or wrong. This research extends the study of labor quantification to the analysis of large-scale complex architecture with this more detailed and disciplined process. The construction industry estimating standards demonstrated here provide archaeologists with a consistent, accurate, and objective means to calculate the labor investment in structures previously too complex to be proficiently analyzed.

Additionally, this research goes beyond the static analysis offered by simply quantifying labor. The application of critical path method scheduling provides researchers the means to estimate the construction time of ancient architecture enabling archaeologists to study the data in dynamic terms and to simulate the effects of various construction and labor organization strategies in their cultural context.

CHAPTER 1
INTRODUCTION

Problem Statement

Modern construction of large architectural and engineering works rely upon a sophisticated array of project planning, management, and simulation systems to generate multiple, dynamic building scenarios based upon techniques that can be productively employed in archaeological analysis of ancient monuments. The aim of this dissertation is to demonstrate the broad applicability and establish a methodology of these analytical systems to the testing of archaeological hypotheses concerning scale of construction, organization of labor, and complexity of social organization.

Civilizations on the north coast of Peru have engaged in building monumental constructions for thousands of years. Hundreds of mounds, pyramids, U-shaped structures, and compounds represent the tangible remains of these prolific builders. One of the challenges for archaeologists is to examine and explain what these passive remains can tell us about the societies that constructed them.

Quantitative labor analysis of architecture, *energetics*, is one method to estimate relative rank and power within or between societies. Energetics' premise is that the scale and complexity of monumental construction is an indicator of the degree of a societies' complexity and its control over resources, including labor. Because of the basic nature of the data, energetic analysis directly and indirectly influences a large body of archaeological theory concerning socio-political organization.

However, there are no standard methodologies at present for quantifying labor expenditures in Andean archaeology, and the current methods are applicable only to basic structural forms, often solid earthworks such as mounds and pyramids or small-scale buildings such as residential units. Due to the lack of practical analytical methods, complex architecture is often described subjectively as "enormous," "vast," or "large-scale," which in the end offers little quantitative value. Consequently, this type of quantification could be misleading and possibly wrong. Archaeologists require an accurate, reliable, reproducible, and objective method to quantify the amount of resources committed to the construction of complex architectural forms.

Yet, even an accurate quantitative estimate of labor is but one component in an integrated approach to evaluating the use of labor in ancient constructions. The energetics approach of converting architecture into its labor equivalence takes a passive view of architecture and yields a static analysis of the effort expended on construction. Knowing *how much* labor was invested in a project is only a partial use of the data. If the goal of archaeology is to elucidate the dynamics of a society, then we need accurate information concerning *how* that labor was deployed and *how long* the construction processes may have taken. The need is for a method to incorporate the static data from labor estimates into a system to simulate the dynamics of the construction process. Social and organizational theories can then be compared and evaluated in a dynamic context.

Summary of Methodology

Prehistoric Andean societies exhibited the ability to muster and control large forces of labor for the purpose of building complex engineering projects as well as constructing some of the largest monuments in the New World. Chan Chan, the capital of the Chimor Empire during the Late Intermediate period (AD 900 to 1470) played a vital role in the evolution of social complexity in the Andes, culminating with the Inca Empire. Located on the north desert coast of Peru, Chan Chan is noted for its elite architecture represented by ten large adobe compounds (*ciudadelas*). Ciudadela Rivero is the most studied compound from an architectural perspective. It is also the smallest and perhaps the final compound built. This research applies modern construction project management planning systems to simulate the construction process of Ciudadela Rivero, in order to quantify the labor expended, and estimate the time of construction under multiple building and labor organization strategies.

Today the use of sophisticated construction project management tools has become standard in building and engineering projects worldwide. Computerized design, estimating, scheduling, and simulation systems provide builders with the ability to compare alternative strategies of construction, labor utilization, resource allocation, and scheduling. This research makes these techniques explicit and demonstrates this integrated approach in an archaeological context. A site-specific study, based upon the architecture of Chan Chan, in the Moche Valley, will assess the relationship of the technological and cultural influences on the planning, staffing, scheduling, and construction of the site. Ciudadela Rivero is best suited for analysis from a construction perspective due to the extensive mapping and existing research.

The creation of a 3-dimensional architectural model of Ciudadela Rivero is a fundamental element of this research. This computerized model is the basis for the application of construction estimating and scheduling tools. In addition to being the source for the physical data of the project, the model provides a context to *experience* the architecture from the point of view of the occupants and to observe spatial relationships from new perspectives enabling fresh interpretations of function and meaning.

The estimating techniques of the construction industry follow a methodical process to determine the labor and material requirements of complex architecture. When utilized in an archaeological context they surmount the limitations of current techniques that are only applicable to mound-like structures and vernacular architecture. This systematic process provides the methodology for the quantitative analysis of the project. The resulting data provides the best measure of the level of effort required to construct a ciudadela and will contribute to theories of scale, power, and rank.

Construction scheduling techniques permit the calculation of overall project duration by simulating and comparing multiple 'what-if" building and resource allocation strategies with respect to task allocation and labor distribution. Defining the parameters of construction scenarios in terms of labor effort, building techniques, and time reveals new information effecting theories of prehistoric labor tax/labor organization, and social organization. This allows simulation of the construction in an ancient Andean framework providing insight into the dynamic aspects of the construction process and testing of labor organizational theories.

This multidisciplinary approach, integrating construction management with archaeology, ethnography, and ethno-history, will open a new perspective into the dynamic analysis of ancient architecture, and our understanding of the evolution of early complex societies.

These project management tools, working in an integrated fashion in a multi-disciplinary approach, provide a unified methodology applicable to the research of other ancient construction projects. They represent the means to transcend the passive estimation of labor invested in a structure by simulating the dynamics of construction, allowing hypothesis testing of issues concerning power, scale, labor utilization, and social complexity.

Historical and Theoretical Background

Site Description

Setting

The north coast of Peru exhibits a unique geographic niche. An extremely arid desert running some 350 km. is bordered on the west by some of the most bountiful and productive marine resources in the world, and on the east by the Andes Mountains. Due to the lack of rainfall, the only sources of water along this desert strip are the rivers carrying runoff from the western slopes of the Andes. The Moche valley is centrally located in this unique environment (Figure 1-1).

Monument building occurred early and often on the coast beginning in pre-ceramic times. Since then, the control of land and water has been a critical element in the development of north coast societies. Located by the sea in the Moche valley, Chan Chan, the capital of the Chimu Kingdom, dominated the entire north coast of Peru during the Late Intermediate period. The expansion of the Chimu Kingdom came to an abrupt end by their defeat and incorporation into the Inca Empire around AD 1470 (Rowe 1948: 42-46). Dominating the urban core of Chan Chan is an area containing 10 monumental adobe enclosures called *ciudadelas* (Figure 1-2), covering an area of 6 square kilometers,

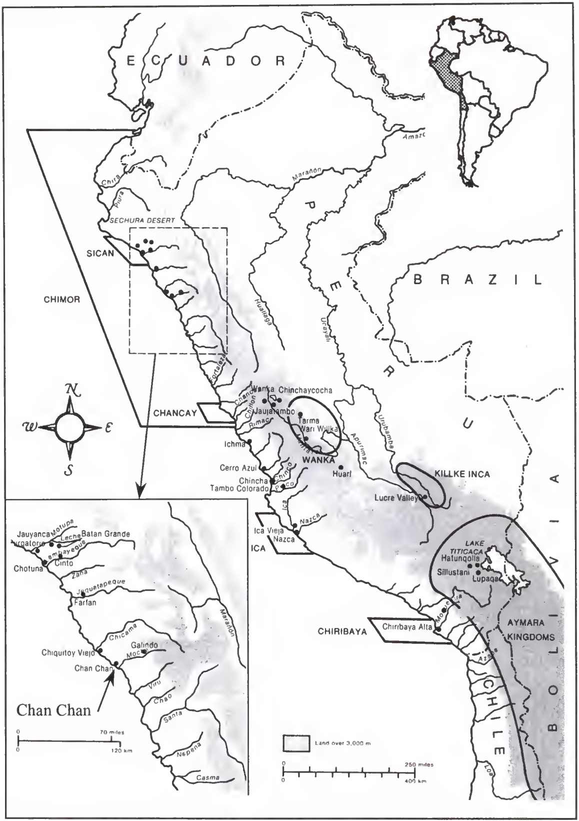


Figure 1-1: General location of Chan Chan. (Moseley 1994)

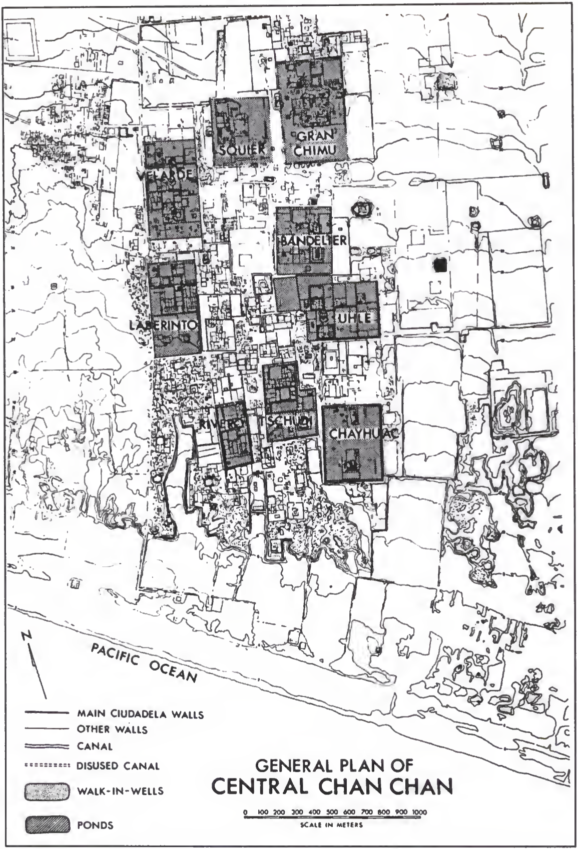


Figure 1-2: Layout of major compounds. (Moseley 1994)

while metropolitan Chan Chan encompasses 20 square kilometers (Moseley 1975a: 219-220). Additionally, the site includes smaller elite compounds, adobe mounds, barrios of small-roomed domestic and craft oriented structures, walk-in wells, and sunken fields.

Social organization

The political foundation of Chimu society rests in divine kingship and nobility, resulting, according to legend, from separate creations from commoners (Rowe 1948: 47). These highly centralized political powers created a social structure of two distinct classes with unequal access to labor, status, and wealth. Economically the state exercised direct control over labor and the production, storage, and distribution of resources (Keatinge & Day 1973: 292; Keatinge & Day 1974: 229; Moseley 1975a; 221) through a hierarchical, secularized bureaucracy.

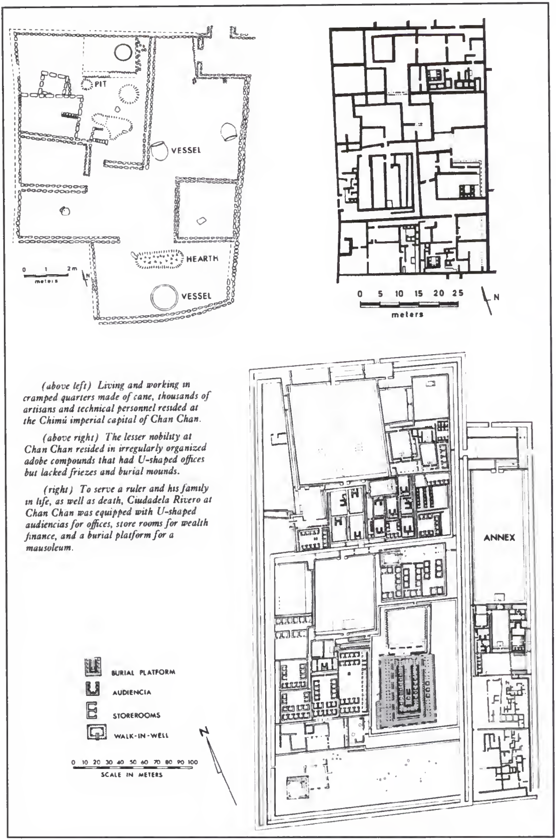
An expansionist state, the Chimu Kingdom, remained a coastal empire (T. Topic 1982: 281; 1990). Although a centralized bureaucracy may not have been necessary to manage rural production (Netherly 1984:247), provincial communities organized along functional lines; each played a specific role in the economic system. Some acted as rural administration centers responsible for maintaining state control over land and water (Keatinge 1974: 78-79), while others produced specialty goods such as chicha or corn beer (Moore 1981: 122).

Architecture

Three classes of architecture at Chan Chan reflect the division of status and state control of the economic systems that underlie Chimu society. These classes include monumental, represented by the ciudadelas, intermediate elite structures, and artisan quarters in the form of small irregular agglutinated rooms (SIAR's) made of mud and cane (Figure 1-3).

The dominant features on the landscape of Chan Chan are the ciudadelas. They served as the administrative center of the kingdom, the royal palaces of the kings and their immediate families, and with the addition of a burial platform, a mausoleum upon their death (Day 1973: 281). Most of the compounds are oriented on a general north-south axis and surrounded by massive adobe walls rising up to nine meters high and as much as half a kilometer in length. Whether the primary function of these massive walls was privacy (Moseley 1975a: 224) or protection (Keatinge & Day 1973: 282), there is little doubt that they still succeed as expressions of power (Conklin 1990: 63) in their conspicuous consumption of labor.

A single entry on the north side of the compounds leads to the first of three sectors. The northern sector consists of entry courts with decorated friezes, a complex of smaller courts, numerous blocks of storerooms, and U-shaped structures called audiencias. The physical proximity of the audiencias to the storerooms was responsible for the primary association of the audiencias as administrative offices and control points for the storage and distribution of goods (Day 1973: 284; Keatinge & Day 1974: 229; Andrews 1974: 242). However, this theory is under scrutiny since it has been demonstrated that based on access patterns and route maps that, "audiencias do not control access to storerooms in the Chan Chan ciudadelas" (Moore 1996: 208). The central sector also includes courtyards, audiencias and storerooms, as well as the burial platforms for the deceased kings. The southern sector, or *conchone,* lacks permanent



(above left) Living and working in cramped quarters made of cane, thousands of artisans and technical personnel resided at the Chimú imperial capital of Chan Chan.

(above right) The lesser nobility at Chan Chan resided in irregularly organized adobe compounds that had U-shaped offices but lacked friezes and burial mounds.

(right) To serve a ruler and his family in life, as well as death, Ciudadela Rivero at Chan Chan was equipped with U-shaped audiencias for offices, store rooms for wealth finance, and a burial platform for a mausoleum.

Figure 1-3: Architecture at Chan Chan. (Moseley 1994)

structures and perhaps housed low-status retainers to the elite. Interactions between sectors is by means of narrow, labyrinth-like corridors making access progressively more restricted as one moves from the northern to the central sector toward the burial platform. The rectangular layout and tripartite internal divisions are seen as having antecedents in the elite residences of the Moche V site of Galindo (Bawden 1982: 317; Topic & Moseley 1983: 162).

The ciudadelas are the architectural expression of the apex of power. Using massive walls, restricted access, and changes in elevation, this purposeful design isolated the elite from commoners, and represents a formal planning tradition that endured hundreds of years. However, while the interpretation of the ciudadelas as a distribution/warehouse facility fits well with the bureaucratic model of Chimu society, it must be noted that on a purely architectural basis the best function for the form may be that of a museum (Conklin 1990: 64).

Those of lesser nobility than the ruling families resided in elite adobe structures designated as intermediate architecture. They were often situated adjacent to and sometimes controlled access to the ciudadelas. Although they did not generally contain burial platforms like the ciudadelas, intermediate architecture had enclosing walls and restricted access, varying numbers of storerooms, audiencias, and wells. Not all of these structures performed the same function. While some were residences, others may have functioned as public meeting places, administrative offices, and/or were involved with the redistribution of goods (Klymyshyn 1982).

The majority of Chan Chan's urban population lived in self-contained barrios along the city's south, west, and northwest sides in the SIAR's. Built as city-like blocks, these cane and cobble structures contained single-family residences and shops. The bulk of the population of the barrios consisted of semi-autonomous craftsmen and artisans (J. Topic 1982: 161; Moseley 1975a: 223) working full time in a guild-like manner (J. Topic 1990: 146). The estimated number of inhabitants of Chan Chan is 30,000 with the residents of the SIAR accounting for approximately 26,000 persons, of which 10,500 were full-time craft specialists (Moseley 1975a: 223; Topic & Moseley 1983: 157; J. Topic 1990: 152). When the Incas conquered the Chimu between AD 1462 and 1470, the Incas took enormous riches in goods, and relocated the Chimu artisans to Cuzco to work directly for the Inca state (Rowe 1948: 44-46).

Theoretical Background

The interpretation of the architecture at Chan Chan contributes significantly to theories of the social, political, and economic structure of the Chimu. The monumental size of the ciudadelas implies the control of mass labor, the spatial layout suggests differences in rank, and the large proportion of space allocated to storage infers centralized control of a redistributive economy. However, there are no reliable estimates of how much labor was involved in constructing a ciudadela, how long it may have taken to build, and what degree of control and coordination was actually required. These data are directly relevant to theories concerning the sociopolitical organization of the Chimu.

Estimates of labor input are useful when theorizing about the organizational level attained by the builders. Examples include Renfrew (1973a; 1973b), who routinely correlates labor expenditure with social development, as does Webb (1977) at Poverty point, and Erasmus (1965) at Uxmal. Arnold and Ford (1980) quantified the labor cost of structures at Tikal to test theories of settlement patterns. Pozorski (1980: 104) estimates that the amount of labor expended during the construction of Huaca de los Reyes "serves to point out that great masses of laborers were not needed to complete construction. Hence, organizational efforts need not be as substantial or as rigid as might be supposed." Patterson (1985: 66), using similar data to Pozorski, likewise calculates labor costs at Huaca La Florida. It took an estimated 2 million person-days working part-time over a span of four centuries to construct the monumental architecture at Cardal (Burger & Burger 1991: 292), thus rejecting the hypothesis that monumental centers were constructed by complex societies.

The methods used for each of these calculations apply to structures that are volumes of earth or small stone structures, involving a minimal number of tasks and productivity rates, and are probably sufficiently accurate for their context. However, quantitative analysis of architecture involving complex design and single episode construction rather than accretion, requires a more detailed and disciplined approach, such as *architectural energetics* demonstrated by Abrams (1994). In analyzing the labor input of structures at Copan, Abrams illustrated the method by subdividing structures into multiple distinct measurable activities, then estimating the labor required for each activity to calculate the total. This research refines and extends Abram's method of architectural energetics by applying construction industry estimating standards to provide accurate, systematic, and reproducible estimates of labor costs on large-scale complex architecture, as represented by the ciudadelas at Chan Chan.

While quantifying labor does provide useful information, it also "emphasizes the passivity of architecture" (Moore 1996: 64). The resultant data are static. All that can be said for certain is that one structure required more labor than another or that the scale and complexity of architecture is a relative indicator of social sophistication. The problem is that the architecture is separated from its behavioral context, so if we intend to study the past in dynamic terms, we need some means to consider the data in dynamic constructs (Bleed 1991: 19 & 32). In short, quantifying labor expenditures is only part of the story. As Kaplan (1963: 401) stated over 45 years ago, ".... unless we can be more precise in our estimates of how these man-hours were distributed over time, any attempts to derive the size or character of political units from the size or number of structures in question is highly dubious."

Fortunately, the construction industry routinely uses methods to simulate multiple building processes that archaeologists can employ to estimate the time parameters of construction under various labor organization models. To gain insight into the dynamic processes involved in controlling labor, archaeologists, much like the potential owners of a building, need to know how much the structure cost and how long it took to build. For Ciudadela Rivero, this research quantifies the static labor expenditure in terms of person-days of effort as well as simulates the dynamics of labor distribution in terms of construction time and labor organization. These data are applied to the theories of one king/one compound under the rule of split inheritance, and dual organization that suggests occupation in pairs. Both of these theories imply that these monumental constructions were built in a timely manner.

Briefly stated, the one king/one compound theory posits that while earlier compounds were occupied for several generations, the latter compounds, were built sequentially and occupied by successive rulers (T. Topic 1982: 282; Moseley 1982: 15; Kolata 1990: 133). Conrad explicitly stated the theory:

> The major compounds of Chan Chan were the palaces of the kings of Chimor. Each ruler built one such structure to house himself, be the seat of government, and serve as the center for the management of his wealth. In accordance with a law of split inheritance the palace passed to the king's corporation of secondary heirs after his death. His principal heir became the next king of Chimor and built a new palace. (Conrad 1982: 108)

A corollary to this theory is that the construction of the new palace would be rapid to the point in being achievable in a timeframe well within the lifetime of a king. Since the ciudadela is the seat of power and administration, it is in the best interest of a new king to build and occupy the ciudadela as rapidly as possible.

The situation becomes even more interesting if you accept the proposition that the Chimu operated on the principle of dual rule with two kings. Dual and quadripartite organization of society is an effective means of obtaining access to resources and labor (Rostworowski 1990: 457; Netherly 1990: 463; Netherly & Dillehay: 1986: 86) and finds architectural expression throughout the Andes. At Chan Chan, the principles of dual rule posit that, rather than sequentially, the last four ciudadelas were built as pairs (Netherly 1990: 483; Moseley 1990: 11; Cavallaro 1988). That, "rapid construction of the last four ciudadelas is compatible with the rise and formulation of quadripartition" (Moseley 1990: 24). This hypothesis is testable to the extent that it requires rapid construction of the last four compounds. Long construction times consuming significant resources could bring this proposition under scrutiny.

Until now, accurate estimates of labor expenditures and construction times did not exist for the ciudadelas at Chan Chan. Clearly, assessments of these elements with respect to the ciudadelas is an example of data driven hypotheses revealing new information previously unavailable. The following section outlines the methods and implications of this research.

Methodology and Data Collection

Overview

This retrospective approach to the construction process, and integration of the design, estimating, and scheduling functions, produces a powerful means of analysis. The design defines what to build, the estimate represents its labor cost, and the schedule simulates the construction strategy and labor distribution, and calculates the project duration. This investigation takes the point of view of the contractor operating within the social structure and technology available during the construction of the ciudadelas at Chan Chan. The subsequent discussion describes the use of contemporary construction management tools and techniques in the context of constructing Ciudadela Rivero.

Design

There can be little doubt that the ciudadelas at Chan Chan are the result of an enduring architectural design. The monumental constructions and hydraulic engineering projects built by the Chimu signify the skills of professional designers (Ortloff et al. 1982: 593; Moseley 1990: 29), as well as the administrative capacity to organize a labor force for their construction.

In the construction industry, the designer provides the contractor with the plans and specifications for the project. The Chan Chan Moche Valley Project produced detailed architectural plans of the ruins of Chan Chan including Ciudadela Rivero (Mackey & Moseley 1974) which serve as the basis of the design. Specifications include type and sizes of material, construction details, methods, and techniques. This information is derived from previous architectural research including Kent Days' (1973) detailed fieldwork on Ciudadela Rivero. Additional research into materials and construction details include adobe bricks (Kolata 1982), burial mounds and remodeling (Conrad 1982), elite architecture (Klymyshyn 1982), and audiencias and roofing (Andrews 1974).

Ultimately, the architecture itself is the best source of data. At the request of Peru's Instituto Nacional de Cultura La Libertad, additional research and field work was conducted by the author at Chan Chan, specifically Ciudadelas Rivero and Tschudi, during May of 2000. The site research consisted of examining, photographing, and measuring the existing ruins to compare and verify the previous architectural plans and research.

The resulting data are the basis for creating a 3-dimensional virtual model of Ciudadela Rivero (Figure 1-4). This architectural model is in sufficient detail to create accurate and workable construction drawings and represents the actual building materials of each element of the model. The model is especially useful for measuring and extracting quantities of material for estimating labor expenditures, and to visualize work plans, staging, and storage areas.

Labor Quantification

A *Scope of Work* (SOW) identifies all activities required to construct the project based upon the plans and specifications. A *Work Breakdown Structure* (WBS) is a hierarchical representation of the scope of work. Beginning at the highest level of the

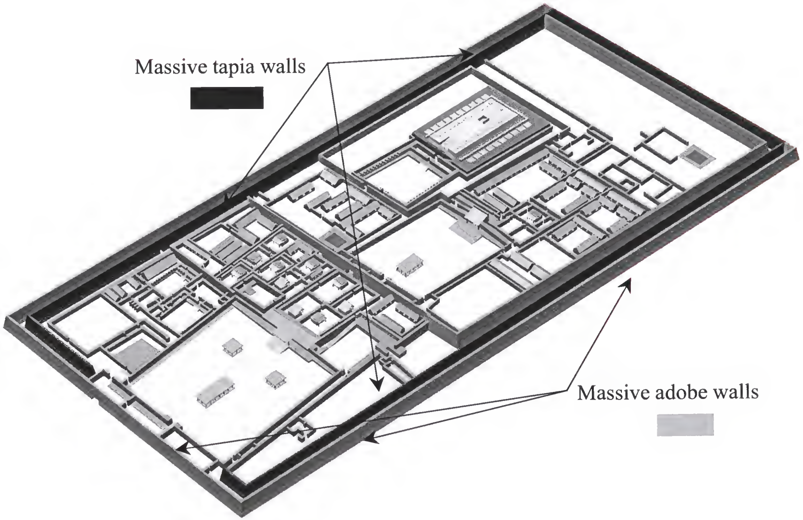


Figure 1-4: Existing configuration of Ciudadela Rivero

project, the WBS divides and sub-divides all of the work into increasingly detailed levels culminating in discrete tasks or *activities*. Each activity involves different time and labor requirements. The virtual model provides accurate measures of material quantities required for each of the activities involved with constructing the ciudadela.

The development of productivity rates begins with an analysis of the structures, tools, construction methods, and techniques available at the time of initial construction. Correlating contemporary productivity information from published construction estimating standards to determine productivity at Chan Chan augments experimental data from previous research. Procedurally, each activity is evaluated in terms of optimum crew sizes and productivity to determine the total work effort and duration. Combining these productivity rates with the material quantities derived from the virtual model yields the total labor requirement for each activity. Summarizing the labor and material quantities of the activities up the WBS hierarchy generates the total project estimate.

Quantifying the labor expenditure for the construction of Ciudadela Rivero provides useful data for comparison purposes. However, the societal implications involved in utilizing these resources and the desire to explore its *meaning* necessitates the consideration of time and the dynamics of construction. In order to study the effects of putting these resources into motion, the project estimate is integrated into the project schedule. This permits modeling theories of labor organization by observing the resource utilization under multiple construction scenarios, and calculating overall project duration.

Scheduling

Critical Path Method scheduling (CPM) is a network-based planning technique for evaluating a group of interrelated activities that constitute a project. Logical relationships between activities determine which control the overall duration of the project, the critical path. CPM is a powerful analytical planning tool widely implemented in the construction industry as a means to simulate and evaluate multiple construction strategies and resource allocation and utilization schemes. This application of CPM presents a versatile tool to dynamically model how resources *might have been used* within the context of prehistoric construction. These practical, problem-solving methods "fit well with the evolutionary interests of many modern archaeologists" (Bleed 1991: 19-20).

Developing a project schedule requires 1) the identification of activities, their resource requirements, and duration, 2) the logical relationships between the activities, and 3) an organizational context for defining construction strategies. The work breakdown structure and estimate provides data for determining activities, crew sizing, and activity durations satisfying the first requirement. Assessments of construction sequences and labor organization provide the balance. Important aspects effecting the logic of construction sequences include the knowledge of the construction techniques and methods used, local building traditions, and labor availability.

Another important source of scheduling information is identifiable in the architecture itself. Items such as wall abutments and structural connections reveal clues to their internal chronologies and phases. This process is well presented in studies at Huaca de los Reyes by Conklin (1985: 139-141), Azangaro by Anders (1991: 183), Niles (1987: 217-229) at Callachaca, and Day (1973, 1982) for Ciudadela Rivero. These types of relationships are useful for determining the order of construction.

Beyond these are sets of relationships resulting from labor allocation strategies that exert a significant influence on the construction strategy. Manipulating these organizational relationships is an important means of simulating realistic building strategies. There is general agreement that a labor or mit'a tax was in place at Chan Chan. Since societies did not use money or any standardized currency, the state extracted *revenue* from the population in the form of labor, often on public works type projects. This form of taxation is characteristic of many prehistoric Andean societies, and was most likely operational during the construction of Chan Chan. There are two approaches applicable to allocating labor under a mit'a tax system. In the work party method, groups of workers perform all of the tasks necessary to produce a measured amount of completed product such as a wall. Task specialization and differentiation occurs when each group performs a single task such as making bricks or plastering. For some time, Andean archaeologists observed evidence of constructing structures in segments (Kroeber 1930: 61 & 78; Willey 1953: 206; Hastings & Moseley 1975; Moseley 1975b: 39). Moseley posits that segmentation is inherent in the design and organization of construction, resulting from the creation of discrete, measurable units of work, carried out in fulfillment of labor obligations (see Moseley 1975c for full discussion). Further, distinct work parties from within the same social group were responsible for a specified quantity of work requiring a series of identical repetitive tasks, i.e., making bricks, hauling them to the site, and setting them in place (Moseley 1975c; Hastings & Moseley 1975: 202-203). Others suggest this theory is not universal, that task specialization and differentiation with one group making bricks, another hauling them, and another setting the bricks, better describes labor organization at some sites (Shimada 1990: 335; Mackey

& Klymyshyn 1981: 104). The power of the scheduling process is the flexibility to model these types of labor strategies to compare their influence and effectiveness on the construction process.

Additionally, tactical options arise such as which had priority, the king's area in the central compound or the more public structures in the northern sector? How much labor would it take to build them concurrently, and which form of labor best fits the situation? Were the massive exterior walls completed before work began on the interior? These alternatives have measurable effects stated in terms of the scale of effort and labor distribution. The extent of these effects will shed light on other issues such as the need to import workers from throughout the region, along with their temporary housing and subsistence, versus using local forces to meet the needs of construction. This research simulates these multiple building strategies and tactics using the work party and the task differentiation model as the basis of comparing the results in terms of organizational complexity, efficiency, resource requirements, and project duration. The flexibility of this type of scheduling permits us to see the influence of social constructs in a dynamic environment in a way previously unavailable.

Significance

This research serves to introduce construction project management practices to the field of archaeology, by demonstrating the methodologies and their applicability to the testing of archaeological hypotheses concerning scale of construction, organization of labor, and complexity of social organization. The methods and processes presented here refine and extend the field of architectural energetics by using construction industry estimating standards to provide accurate, systematic, and reproducible estimates of labor costs on large-scale complex architecture. Further, it introduces the concepts of construction scheduling which can dynamically simulate the construction process and estimate construction times of ancient architecture.

Ultimately this research provides an accurate estimate of the labor expenditure for the construction of Ciudadela Rivero, and establishes reasonable parameters for construction times under multiple construction strategies. The ability to simulate the distribution of these resources over time is the result of a multi-disciplinary research design by applying the tools of the construction industry in an Andean context. The quantification of construction time and labor cost is pertinent to issues of social and administrative organization and complexity. If the ability to mobilize large work forces was the foundation of prehistoric Andean society (Schwartz 1982: x), then this research has direct relevance to archaeologists at a fundamental level.

CHAPTER 2
PRINCIPLES OF CONSTRUCTION PROJECT MANAGEMENT

Introduction

Overview

The purpose of this chapter is to describe and demonstrate the capabilities and applicability of construction project management techniques to the archaeological community. It addresses techniques used to determine how much labor was invested in the construction of complex ancient architecture and how long projects took to build under different labor organizational theories, using a generic Chimu storeroom, typical of those found at Chan Chan, as an example.

This chapter addresses the topics of 1) defining a *scope of work*, 2) *estimating*, 3) *scheduling*, and 4) *advanced analysis tools*. Under *scope of work* is a description of the storeroom design, a general overview of its materials and construction, and the process of explicitly defining each work task or activity necessary to build the storeroom.

From an archaeological perspective, the only meaningful measure of cost is the estimated direct labor in terms of labor hours. The *estimating* portion begins with the process of quantifying the material requirements of each activity followed by a detailed discussion of construction materials, their sources, methods of manufacture or fabrication, and construction techniques, in order to develop estimated productivity rates. The process culminates with the calculation of the project estimate that quantifies the total amount of labor invested in constructing the storeroom.

Simulating the construction process to determine the project length and resource requirements appears in the *scheduling* section. It illustrates the progression in developing construction schedules by determining activity durations, identifying relationships between activities to produce logic diagrams, and allocating labor resources to simulate multiple labor organizations. The resulting schedules represent the estimated construction time of the storeroom under the task specialization and work party theories.

The final section explores the use of *advanced analysis tools* involving complex approaches in the areas of resource management and schedule logic, to fine-tune the schedules to more accurately model the construction process. Attempting to recreate prehistoric circumstances always entails a degree of uncertainty. The section concludes by illustrating a statistical method of quantifying the uncertainty of the estimating and scheduling data in terms of confidence levels.

The following chapter then applies this methodology to the construction of Ciudadela Rivero.

Background

The ever-increasing complexity of modern engineering and building projects requires the construction industry to use systematic processes to plan and coordinate the numerous organizations and thousands of inter-related tasks required to construct these structures. These planning techniques necessitate breaking the project down into a series of manageable parts, determining the cost of each part and their time requirements, and then analyzing numerous scenarios concerning alternative sequences of installation.

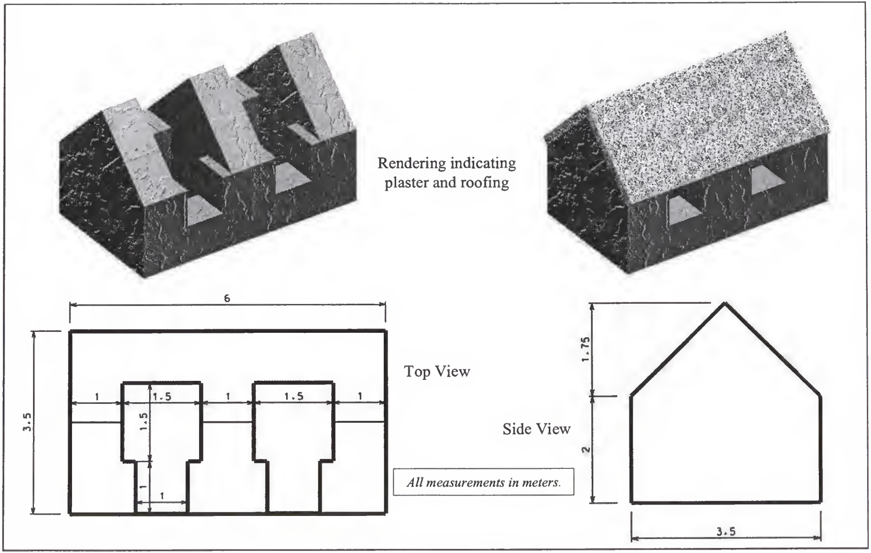
Successful contractors are those who use these tools to accurately estimate the cost of projects, develop feasible work plans to execute the construction, and control the expenditures of time and resources in a judicious and efficient manner in order to make a reasonable profit. The project management techniques described in this chapter are in extensive use by commercial contractors worldwide. For archaeologists, when used retrospectively, they represent the best available set of tools applicable to the quantification of labor cost and construction times of ancient architecture.

Scope of Work

The sum total of all deliverables that make up a project is the *Scope of Work.* Typically, the plans and specifications serve to describe the structure explicitly in terms of material types, sizes, amounts, quality, and location in a project. Complete understanding of what is and is not included in the scope of work is critical to the development of a successful construction strategy.

Sample Project

The project consists of a generic two-bay storeroom, typical of Chimu construction at Chan Chan (Figure 2-1). The shell of the storeroom is 3.5 m wide and 6 m long. The walls are made of sun-dried adobe bricks approximately 19 cm x 48 cm x 10 cm. The walls have a 10 cm coating of mud plaster on all exposed surfaces, and the floor is a 5 cm thick layer of clay. The roof structure is made of two species of native bamboo, cana de guayaquil and cana brava. Beams of 10 cm diameter cana de guayaquil are bound to perpendicular layers of 3 cm diameter cana brava, and topped with a 5 cm layer of grass and mud (Figure 2-2). For purposes of this example, assume the site is level, the soil used for plaster and flooring is available on-site, and the raw materials for adobe and cana are accessible within a 250 meter radius of the site.



All measurements in meters.

Figure 2-1: Storeroom plan.

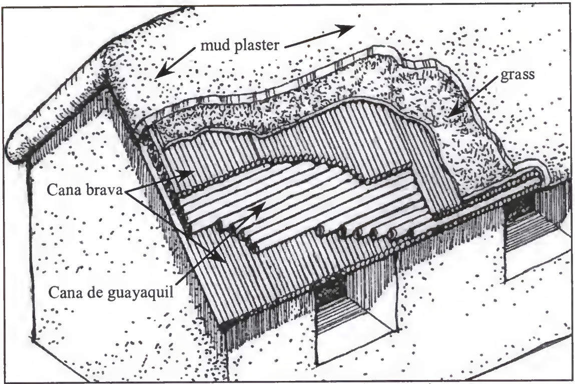


Figure 2-2: Detail of storeroom roof construction.

Work Breakdown Structures

A *Work Breakdown Structure* (WBS) is a hierarchical representation of the scope of work. A WBS is deliverable-oriented where each descending level divides and subdivides the work into an increasingly detailed definition of a project's components culminating in discrete tasks or *activities*. The WBS defines and organizes the project elements to clearly identify deliverables and to report and summarize cost and schedule data at various levels of detail. The level of detail is subjective and is a function of the ability and desire to estimate quantities, costs, and time.

A simple WBS representing the storeroom (Figure 2-3) consists of two major components: the adobe shell and the cana roof. Subsequently each component is subdivided into separate and distinct tasks. The construction of the adobe shell requires manufacturing the bricks and transporting them to the site, followed by their installation in the wall. The walls need to be plastered and the clay floor placed. To build the roof both cana brava and guayaquil must be gathered and delivered to the site. In this instance, the roof consists of a series of panels built on the ground then put into place and plastered.

These activities are discrete, quantifiable, and represent a unique place in time. The sum of these activities represents the total scope of work for the construction of the storeroom.

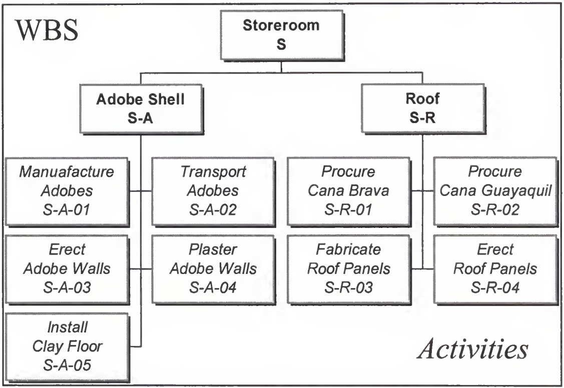


Figure 2-3: Work Breakdown Structure for storeroom.

Estimating

Estimating is the function of approximating the cost of the project prior to construction. From the owner's perspective, the cost of a project may include land, design fees, permits, specialized equipment, and furnishings, in addition to the cost of the building. For the contractor, cost includes the direct and indirect expenses incurred building the structure. Direct costs consist of items such as labor, material, and equipment purchase or rental, while indirect costs comprise supervision and overhead expenses. For archaeological analysis, direct costs are the best representation of labor investment. The costs of items such as land, fees, and equipment are irrelevant and unknowable in a pre-historic context and the level of supervision can only be guesstimated. However, the labor expended procuring, manufacturing, and installing materials is quantifiable in a methodical and reproducible manner.

Quantity Survey

The quantity of installed materials is the basis for determining the labor cost of each activity. The *quantity survey* delineates the measured quantities of material in a manner consistent with the activities, in the proper units of measure used for estimating.

From the WBS, building an adobe wall involves manufacturing adobes, transporting them to the site, and installing them in the wall. The common unit of measure for estimating the productivity of these activities is volume. An item of interest, but not essential for determining cost, is the number of adobe bricks made. For plastering and clay flooring the unit of measure is square meters. Estimating the construction of the roof requires consideration of the design which indicates a series of four 2.5 m x 3 m panels. The fabrication and erection activities are estimated on a per-panel basis. However, the cost of procuring the cana requires calculating the total length in meters of cana cut and delivered to the site. Using the design shown in Figures 2-1 and 2-2 the quantity survey (Table 2-1) sets up a format to calculate the quantities of installed materials for the storeroom.

Table 2-1: Quantity survey of storeroom.

Item Description	No.	Dimensions			Total	Unit of Measure	Conversions		Total Estimated Quantity	U/M
		Length	Width	Height			Rate			
Storeroom										
Adobe Walls - Standard adobes 24cm x 10cm x 19 cm										
Front Wall	1	6.00	1.00	2.00	12.00	m^3				
Less openings	(2)	1.00	1.00	1.00	(2.00)	m^3				
Rear Wall	1	6.00	1.00	2.00	12.00	m^3				
Side Walls	3	1.50	1.00	2.00	9.00	m^3				
Gables 3 each / 2 for triangular section	1.5	3.50	1.00	1.75	9.19	m^3				
Total Volume of Adobe Walls					40.19	m^3				
			Total Volume of Adobes						40.2	m^3
			Total Number of Adobes				172	adobes/m^3	6,912	Ea.
Plaster Walls - 10 cm										
Exterior										
Front Wall	1	6.00		2.00	12.00	m^2				
Less openings	-2	1.00		1.00	-2.00	m^2				
Rear Wall	1	6.00		2.00	12.00	m^2				
Side Walls	3	1.50		2.00	9.00	m^2				
Gables 3 each / 2 for triangular section	1.5	3.50		1.75	9.19	m^2				
Interior										
Room	2	4.50		2.00	18.00	m^2				
Openings	2	3.00		1.00	6.00	m^2				
Total Area of Plastering					64.19	m^2				
			Total Area of Plastering						64.2	m^2
Clay Flooring - 5 cm										
Rooms	2	1.50		1.50	4.50	m^2				
Total Area of Clay Flooring					4.50	m^2				
			Total Area of Clay Flooring						4.5	m^2
Roofing - Cana										
Total Roofed Area	4	3.00	2.50		4.00	Each				
			Total Number of Panels						4	Ea.
			Total Area of Panels						30	m^2
			Cana de guayaquil - 10cm dia.				2	meters / m^2	60	meters
			Cana brava - 3cm dia.				60	meters / m^2	1800	meters

The materials contained in the adobe walls, plaster, flooring, and the roof, are measured and converted into the required units of measure. The next step in the process is the development of productivity rates for those items identified in the quantity survey. Applying the productivity rates to the estimated quantities yields the labor requirements for each activity; the sum of which is the total project cost in labor hours.

Productivity - Unit Rates

Productivity is the cost per unit of output produced measured in terms of labor hours, and referred to as unit rates. The estimator's job is to develop and apply the unit rates to the quantity survey to calculate the project estimate. The development of productivity rates for ancient construction is often linked to field experiments designed to replicate ancient tasks, which seemingly limits the availability of useful data. This section demonstrates how to develop unit rates using a variety of data from existing sources and in the process determine which activities might be suitable for field experiments.

Unit rates are largely a function of the tools and techniques employed to perform a task. One of the challenges of analyzing ancient construction is determining these tools and techniques. The best evidence of techniques is in the architecture itself and building traditions passed down through generations. Additionally, while approaches to construction may vary widely by region and time, similar solutions to similar problems are prevalent worldwide and examination of alternative solutions is a sensible tactic.

Contractors often maintain historical cost data from previous projects to estimate the cost of similar work on future projects. This historical data, adjusted for local conditions, is generally very accurate and often highly proprietary. Fortunately, data from field experiments performed by archaeologists are not proprietary and often provide valuable statistics adaptable to the study site.

Sometimes the old ways are the best ways and techniques that endure for generations are still in use today. Contemporary practitioners are particularly helpful in this regard and provide a first-hand perspective unavailable from other sources.

Construction is not a wholly automated process and many of the work operations used in the past are still in use at present. Commercially published construction cost guides, compiled from years of sampling, contain average productivity rates for a variety of manual operations. These rates provide a good approximation of the work required to complete a task. Construction is not a routine repetitive business such as manufacturing, in that each project is unique. Therefore, as with historical data, productivity data resulting from average unit rates representing many projects must be adjusted to meet the requirements of the specific site.

Finally, lacking any other source material, the estimator mentally constructs the activity step by step, and based upon their best knowledge and experience, predicts the productivity rate, the proverbial *best guess*. The degree of concern over weak data is relative to the activity's overall contribution to the whole. A best guess of an item of little importance has a negligible effect on the total project, where identifying critical areas of weak or missing data serves to guide future research in productive directions.

The issue of physical work capacity is recognized but not addressed in this research. Topics such as physical size, sex, age, lung capacity, caloric intake, etc., are important factors affecting production. To address one factor invites consideration of the others where no clear answers exist. The primary purpose of this research is to demonstrate a methodology and establish a reasonable estimate of labor investment, not to examine the biological issues of a culture.

An appropriate and effective approach to estimating prehistoric construction is identifying the range of probable unit rates for each activity. Multiple sources of data are useful for bracketing the probable productivity rate in terms of high and low expectations. In this method, the *most likely* value represents work progressing as expected with normal progress under normal conditions. This is the rate most probable to occur and treated as deterministic in most analyses. However, conditions are not always ideal and estimates are just estimates. To the contractor, this uncertainty represents an identifiable risk in terms of the probability of completing a project on time and within budget. Statistical modeling techniques use a range of unit rates and perform thousands of iterations with the potential variables to calculate the probable ultimate cost based on the frequency of the outcomes. The *optimistic* estimate sets one end of the productivity range and assumes that the work proceeds with better than expected results, while the *pessimistic* estimate sets the other end with poor productivity due to unforeseen or unusual difficulties. Unless statistical analyses are contemplated, only the *most likely* rates need to be derived.

The following pages detail the development of these ranges of unit rates for the items identified in the quantity survey. Each begins with a discussion of the construction techniques involved, followed by the data used to establish the unit rates. Additionally, each rate includes a determination of optimum crew sizes for each task.

Manufacturing adobes

Traditional methods of making sun-dried adobes are essentially unchanged for countless generations in many parts of the world. Since the bricks are not kiln hardened, they are inherently unstable and only slightly stronger than the original soil. The adobes at Chan Chan are unstabilized, with no binders such as straw that helps control shrinkage.

The adobe-making process involves combining a sandy clay soil and water in a shallow mud pit, then mixing with a shovel or hoe, or by foot treading. Wooden forms capable of making single or multiple bricks are set on level ground and the interior of the form moistened with water. The adobe maker *(adobiero)* drops or throws the mixture into the form(s), kneads it to fill the corners and remove air bubbles, then levels the top with a stick or board. The forms are removed immediately, rinsed, and prepared for the next charge of mud (Figure 2-4). In low humidity climates, the initial drying time is two to three days (McHenry 1984: 63). After this initial period the bricks are tipped on edge, trimmed, and continue to cure an additional few days. Adobes are stacked before installation (Figure 2-5). While the full curing process occurs in ten to twenty days, adobes may be transported and installed after five to seven days (Wilson: pers. com.[1]).

Productivity rates for making adobes vary by source in the composition of crews and tools used. Table 2-2 represents a format that brings each estimate to a common unit of measure, allowing for adjustments as needed. The raw data of the first two sources state that two workers with a wheelbarrow, hose, and a 4-unit form make between 350 and 500 (35 cm x 10 cm x 25 cm) bricks per 8-hour day. An informant working in the Moche Valley, when questioned during this field research, indicated that he mixes and makes 300 bricks in 3 days, with a single brick form, carrying his own water about 50 meters. The estimated unit rates reflect extending and converting the adobes made per day into hours per cubic meter of bricks produced. The rates range from 3.5 to 8 hrs/m^3.

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[1] Quentin Wilson, Instructor of Adobe Construction, Northern New Mexico Community College

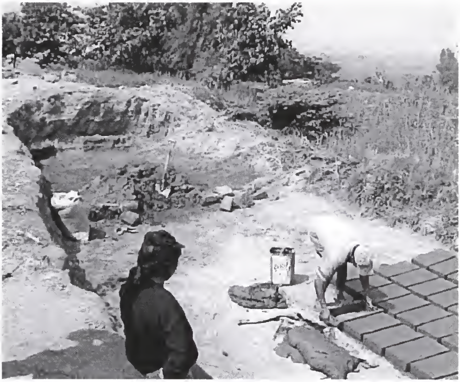


Figure 2-4: Informant making adobes in the Moche Valley.

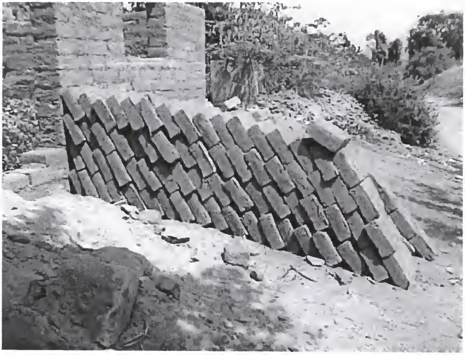


Figure 2-5: Stacked adobes ready for use.

Table 2-2: Productivity - Manufacturing adobes.

Rates for adobe production based upon hand-carrying materials and a 4-unit form.
Average adobes at Rivero: 24cm x 11cm x 19cm (approx. vol. = 0.005 m^3)
Adobes in survey: approx. 35cm x 10cm x 25cm (approx. vol. = 0.01m^3)

Source	No. of Workers	Hours Worked	Total Hours	Number of Adobes Made	Volume of Adobes Made	Unit Rate
Raw Data						
Wilson	2	8	16	500	4.59 m^3	3.49 hrs/m^3
McHenry	2	8	16	350	3.21 m^3	4.98 hrs/m^3
Informant	1	24	24	300	3.00 m^3	8.00 hrs/m^3
Adjusted Rates						
Wilson	3 [1]	8	24	500	4.59 m^3	5.2 hrs/m^3
McHenry	3 [1]	8	24	350	3.21 m^3	7.5 hrs/m^3
Informant	1	24	24	345 [2]	3.45 m^3	7.0 hrs/m^3

[1] Raw data based upon 2 persons with a wheelbarrow, hose, and a 4-unit form
Add 1 extra person for manual transport of mud and water.

[2] Raw data based upon 1 person with no wheelbarrow and a 1-unit form
Increase output by 20% to compensate for 1 unit form

Recap: Manufacture Adobes				Number of average sized adobes made per hour
Crew Size	**3-5**	**Adobieros**		
Productivity Range			**%**	
Optimistic	**5.2**	hours per cubic meter per worker	**-25%**	**38**
Most Likely	**7.0**	hours per cubic meter per worker	**0%**	**29**
Pessimistic	**7.5**	hours per cubic meter per worker	**7%**	**27**

(Wilson 2000: pers. com.; McHenry 1984: 67)

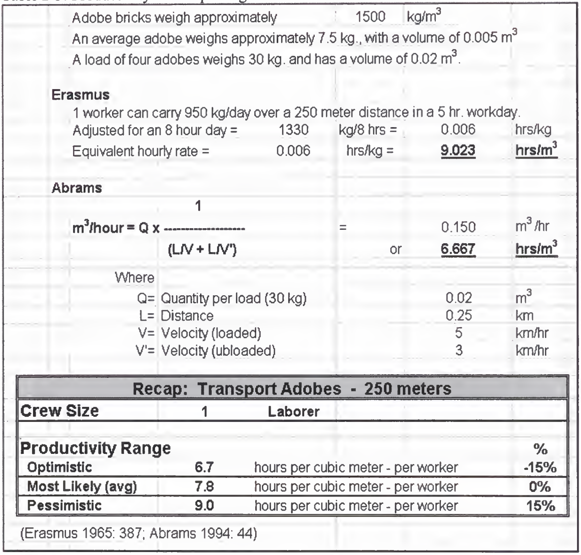
However, the makers of adobes at Chan Chan did not have a wheelbarrow nor as convenient a source of water as a hose like the first two estimates. Conversely, they must certainly have used at least a 4-unit form, unlike the informant, due to the mass production requirements of the project. In order to more closely replicate the techniques used by the Chimu, each of the estimates needs refinement. One person added to the first two crews allows for manual transportation of material and the informant's production raised by 20% to reflect the increased productivity of using 4-unit forms. These adjustments are subjective and depend on construction experience and confidence in the initial data. The resulting recap indicates the range of productivity expected to manufacture adobes in terms of *optimistic, most likely, and pessimistic* unit rates. The informant's productivity is accepted as the *most likely* rate since it is more conservative than the average and most closely represents the actual methods used by the Chimu. The data indicate that each worker produces approximately twenty-nine average sized adobes per hour, with an optimum crew size of three to five workers. In terms of productivity, the *most likely* unit rate for each worker is 7.0 hours per cubic meter.

Transporting adobes

Manual transportation of material is a function of weight and distance. Mud bricks, the size of average adobes at Rivero, weigh approximately 7.5 kg. each (McHenry 1984:65; Norton 1997: 38), with a load of four adobes weighing 30 kg. For purposes of this example, assume the adobe making area is 250 meters from the site of the storeroom. Table 2-3 delineates the productivity rates derived from experimental sources for a 250-meter hauling distance.

Erasmus' research at Uxmal (1965) involved performing various manual transportation experiments using workers in Sonora, Mexico to simulate Maya labor productivity. Rock-carrying experiments yielded productivity rates for manually transporting weights over distances with the raw data using a 5-hour workday due to the strenuousness of the task and oppressive tropical climate. According to these data, a worker can transport a total of 950 kilos over a 250-meter route in a 5-hour day, carrying a weight of 28 kilos per trip. While the work is no less strenuous at Chan Chan, the climate is more hospitable and terrain less hazardous. Erasmus' rates are refined to allow an increased total for an 8-hour workday, tempered for a drop in productivity in the later hours. The revised productivity rate using this data is approximately 9 hours per cubic meter for a 250-meter trip.

Table 2-3: Productivity - Transporting adobes.



Adobe bricks weigh approximately 1500 kg/m^3

An average adobe weighs approximately 7.5 kg., with a volume of 0.005 m^3

A load of four adobes weighs 30 kg. and has a volume of 0.02 m^3.

Erasmus

1 worker can carry 950 kg/day over a 250 meter distance in a 5 hr. workday.

Adjusted for an 8 hour day =	1330	kg/8 hrs =	0.006	hrs/kg
Equivalent hourly rate =	0.006	hrs/kg =	**9.023**	**hrs/m^3**

Abrams

$$m^3/hour = Q \times \frac{1}{(L/V + L/V')} = 0.150\ m^3/hr \quad \text{or} \quad \underline{6.667}\ \underline{hrs/m^3}$$

Where

Q=	Quantity per load (30 kg)	0.02	m^3
L=	Distance	0.25	km
V=	Velocity (loaded)	5	km/hr
V'=	Velocity (ubloaded)	3	km/hr

Recap: Transport Adobes - 250 meters

Crew Size	**1**	**Laborer**	
Productivity Range			**%**
Optimistic	**6.7**	hours per cubic meter - per worker	**-15%**
Most Likely (avg)	**7.8**	hours per cubic meter - per worker	**0%**
Pessimistic	**9.0**	hours per cubic meter - per worker	**15%**

(Erasmus 1965: 387; Abrams 1994: 44)

A second method for estimating productivity uses a standard formula derived from United Nations' experiments as presented by Abrams in his study of energetics of Maya structures (1994: 44). The formula, shown in Table 2-3, accounts for weight of the load, speed of the worker loaded and unloaded, and the distance carried. The results of the calculation yield unit rates of 6.7 hours per cubic meter for a 250-meter trip.

Since both sources of data are reasonably consistent in terms of productivity, the *most likely* rate equates to a simple average of the two. Carrying materials is a singular task so the crew size is simply measured as one person.

Adobe installation

Construction of adobe walls uses simple, time-tested techniques that emphasize quantity over quality, strength over skill. Most walls at Ciudadela Rivero alternate courses in a runner-header bond (Figure 2-6) with mortar applied to only the top surface of the courses. The curing rate of the adobes and the mortar are the primary limiting factors to the speed of raising a wall. Moisture from uncured adobes and/or mortar must migrate to the surface to evaporate, otherwise a compression failure occurs and the wall collapses. In the arid climate of the north coast of Peru adobes achieve a full cure in ten to twenty days, though placement may occur within a week of manufacture, with final curing taking place in the wall, providing the coursing is not too rapid (Wilson: pers. com.). Similarly, too many courses placed upon uncured mortar may also cause compression failure and collapse of the wall. A rate of two to three courses per day of the relatively tall adobes at Chan Chan is adequate to allow the moisture in the core to evaporate.

To build the walls of the storeroom, string lines mark the perimeter, and the corners are built up first (corner leads). Workers then fill-in the sections between the corners in courses following the string lines (Figure 2-7). On thick walls workers simply stand on the previous courses and work backwards placing the bricks and mortar as they go. Workers pass the bricks and mortar up to the mason with minimal or no scaffolding on walls up to 3 meters in height.

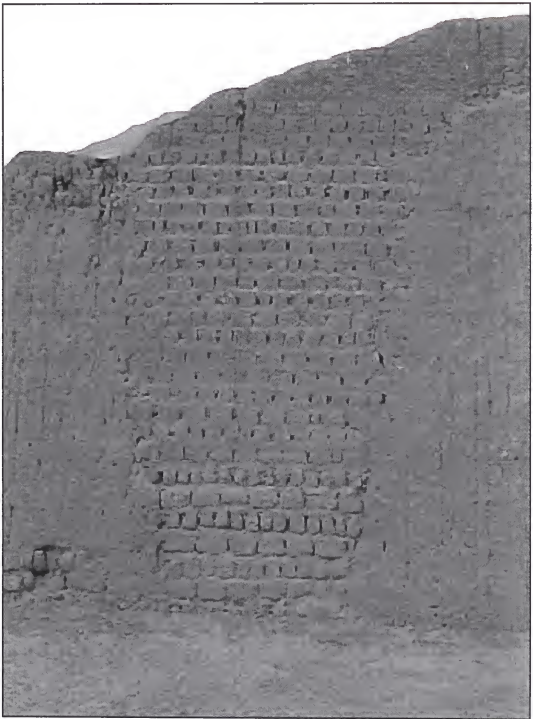


Figure 2-6: Runner-header bond in massive wall at Ciudadela Tschudi.

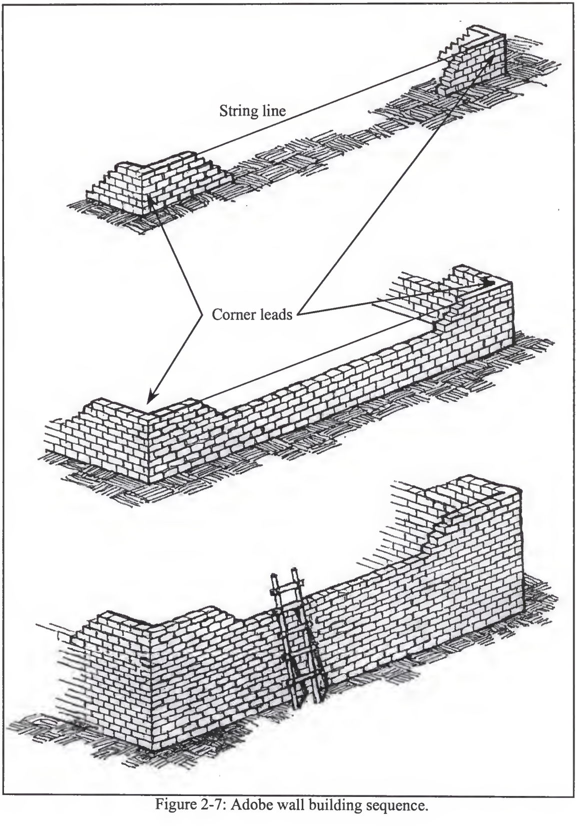


Figure 2-7: Adobe wall building sequence.

Since adobe construction remains essentially unchanged from the time of the Chimu, contemporary sources provide a good starting point. One published standard estimates placement of 555 adobes (35 cm x 10 cm x 25 cm) by a 5-person crew, in eight hours, while Wilson (pers. com.) experiences a rate of 500 bricks with a 3-person crew (Table 2-4). In order to accommodate varying brick sizes, the number of bricks are converted into their equivalent volumes. This yields a reasonably accurate measurement of productivity across the range of brick sizes. However, each assumes the use of a wheelbarrow, a convenient water source, and a machine mixer for mortar. Since the Chimu employed only manual methods, the addition of two workers to each crew adjusts the rates to take into account manual transportation and mixing of materials. The resulting data from both sources are relatively consistent and form the upper and lower limit of the productivity range. The *most likely* rate of 10 hours per cubic meter of wall is the average, with an optimum crew of 4 to 6 workers, depending on the size of the wall.

Table 2-4: Productivity - Adobe installation.

Source	No. of Workers	Hours Worked	Total Hours	No. of Adobes Installed	Volume of Adobes Installed	Unit Rate
Raw Data						
Wilson	3	8	24	500	4.59 m^3	5.23 hrs/m^3
Means	5	8	40	555	5.09 m^3	7.85 hrs/m^3
Adjusted Rates						
Wilson	5 [1]	8	40	500	4.59 m^3	8.72 hrs/m^3
Means	7 [1]	8	56	555	5.09 m^3	11.00 hrs/m^3

[1] Raw data based upon a wheelbarrow, hose, machine mixer for mortar
Add 2 extra persons for manual mortar mixing and transport of mud and water.

Recap: Adobe Installation			
Crew Size	**4 to 6**	**Masons**	
Productivity Range			**%**
Optimistic	**8.7**	hours per cubic meter per worker	**-12%**
Most Likely (Average)	**9.9**	hours per cubic meter per worker	**0%**
Pessimistic	**11.0**	hours per cubic meter per worker	**12%**

No. of average sized adobes Installed per hour
23
20
18

(Wilson 2000: pers. comm.; RSMeans 1999: 134)

Plastering

The walls of the storeroom require a 10-cm thick coat of mud plaster estimated in terms of square meters of surface. The contemporary construction material most analogous to this type of coating is stucco. Modern techniques use a three-coat process to build up the thickness on the wall as compared to the single coat hand-applied method used by the Chimu. Published rates for applying stucco on masonry range from 0.3 to 0.5 hours per square meter (Table 2-5). However, the use of higher quality materials and hand tools provide a significant advantage over the hand pressing method used by the Chimu, so the rates are adjusted by a factor of two. This adjustment also takes into account the minor scaffolding or steps requirements to reach walls up to 3 meters high. While a simple factor of two is not an exact figure, it is a reasonable rate until experimental data provide a better one.

The resulting recap indicates the range of productivity in terms of *optimistic, most likely, and pessimistic* unit rates. The *most likely* unit rate chosen is 0.83 hours per square meter since it is more conservative than an average. The optimum crew size is two workers, a plasterer and a helper.

Clay flooring

The floor of the storeroom consists of a 5-cm layer of compacted soil. Preparing the floor is a 1-person task accomplished by breaking up the top surface of the floor, adding water, and re-compacting the soil. The most comparable contemporary published rate applies to placing a 5-cm layer of compacted mortar to receive paving bricks (Table 2-6). Being the only source of data, the rate is considered *optimistic*, and is factored upwards by 10% and 25% for the *most likely* and *pessimistic* unit rates respectively.

Table 2-5: Productivity - Mud plaster.

Source	No. of Workers	Hours Worked	Total Hours	Total Area		Unit Rate	
Dodge	2	8	16	32.65	m^2	0.49	hours/m^2
Means	6	8	48	167.00	m^2	0.29	hours/m^2
Walker	2	0.416	0.832	2.00	m^2	0.42	hours/m^2

Adjusted Rates	Factor the unit rates by 2						
Dodge						0.98	hours/m^2
Means						0.57	hours/m^2
Walker						0.83	hours/m^2

Recap: Plaster (Stucco)			
Crew Size	2	Plasterers	
Productivity Range			%
Optimistic	0.57	hours per square meter - per worker	-31%
Most Likely	0.83	hours per square meter - per worker	0%
Pessimistic	0.98	hours per square meter - per worker	18%

(Dodge 1977: 167; RSMeans 1998: 224; Walker 1947: 1130)

Table 2-6: Productivity - Clay flooring - 5 cm.

Source	No. of Workers	Hours Worked	Total Hours	Total Area		Unit Rate	
Means	2	8	16	18.60	m^2	0.86	hours/m^2

Recap: Clay Flooring			
Crew Size	1	Laborer	
Productivity Range			%
Optimistic	0.86	hours per square meter - per worker	0%
Most Likely	0.95	hours per square meter - per worker	10%
Pessimistic	1.08	hours per square meter - per worker	25%

(RSMeans 1999: 67)

Procuring and transporting cana

Used primarily as roofing, supports over wall niches, and decorations, both cana brava and cana de guayaquil (Figure 2-8 & 2-9) were readily available to Chimu builders. These native grasses provide excellent structural elements such as columns, beams, and scaffolding due to their high strength to weight ratio (McClure 1953: 13-15). This storeroom example requires cana for fabrication of the roof panels. The larger cana de guayaquil serves as roof beams with cana brava as the covering.

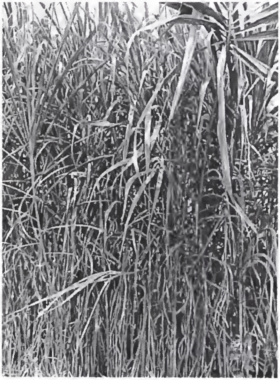


Figure 2-8: Cana brava.

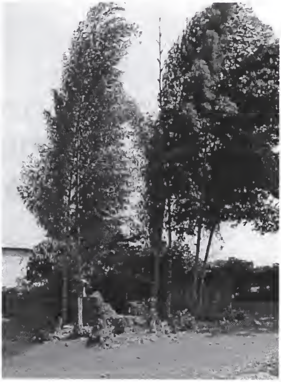


Figure 2-9: Cana de guayaquil.

Delivering cana to the site involves harvesting and transportation, with the same workers generally performing both tasks. For estimating purposes, it is more practical to combine these two operations into a single composite unit rate from the data derived in Tables 2-7 and 2-8.

Harvesting cana includes felling, trimming, cutting, and stacking. Productivity rates vary widely throughout the world due to varying species, density of the grasses, and accessibility of the harvesting site. Studies conducted by the United Nations (Chandra 1975) established an average, all-inclusive rate. Table 2-7 shows the development of this rate for cana brava, based on a weight of 0.5 kg/m. Since the productivity is already an average, it serves as the *most likely* rate allowing for a relatively wide range in the *optimistic* and *pessimistic* values.

Workers carry the cana in bundles on their backs or by dragging it on the ground. For this example, the cana is available within a 1000-meter radius of the site, and a worker can carry a load of 30 kg. The process of calculating the productivity of transporting cana (Table 2-8) uses the same formulas employed previously to calculate adobe transportation. The composite rate (Table 2-9) adds the procurement and transportation costs into a single rate. Table 2-10 shows the corresponding composite rate for cana guayaquil.

Table 2-7: Productivity - Procuring cana brava - 3-cm diameter.

Source	**No. of Workers**	**Hours Worked**	**Total Hours**	**Total Length**		**Unit Rate**	
Chandra	1	8	8	500	m	0.016	hours/m

Cana Guayaquil weighs approximately 0.5 kg/m. *250kg total*
Includes felling, trimming, cutting, and stacking.

Recap: Procuring Cana Brava			
Crew Size	1	**Cana worker**	
Productivity Range			**%**
Optimistic	0.012	hours per meter - per worker	**-25%**
Most Likely	0.016	hours per meter - per worker	**0%**
Pessimistic	0.020	hours per meter - per worker	**25%**

(Chandra 1975: 25)

Table 2-8: Productivity - Transporting cana brava.

Erasmus

1 worker can carry 250 kg/day over a 1000 meter distance in a 5 hr. workday.

Adjusted for an 8 hour day =	350	kg/8 hrs =	0.023	hrs/kg
Equivalent hourly rate =	0.023	hrs/kg =	**0.011**	**hrs/meter**

Abrams

$$\text{m/hr} = Q \times \frac{1}{(L/V + L/V')} = 112.500 \text{ meters/hr or } \mathbf{0.009} \text{ hrs/meter}$$

Where

Q=	Quantity per load (30 kg)	60	meters
L=	Distance	1	km
V=	Velocity (loaded)	5	km/hr
V'=	Velocity (ubloaded)	3	km/hr
H=	Hours per day	1	hrs.

Recap: Transporting Cana Brava - 1000 meters			
Crew Size	1	**Cana Worker**	
Productivity Range			**%**
Optimistic	**0.009**	hours per meter - per worker	**-13%**
Most Likely (Average)	**0.010**	hours per meter - per worker	**0%**
Pessimistic	**0.011**	hours per meter - per worker	**13%**

(Erasmus 1965: 387; Abrams 1994: 44)

Table 2-9: Productivity - Procure and transport cana brava 1000 meters.

Composite Rate			
Crew Size	**1**	**Cana Worker**	
Productivity Range			**%**
Optimistic	**0.021**	hours per meter - per worker	**-20%**
Most Likely	**0.026**	hours per meter - per worker	**0%**
Pessimistic	**0.031**	hours per meter - per worker	**20%**

Table 2-10: Productivity - Procure and transport cana de guayaquil 1000 meters.

Composite Rate			
Crew Size	**1**	**Cana Worker**	
Productivity Range			**%**
Optimistic	**0.107**	hours per meter - per worker	**-21%**
Most Likely	**0.135**	hours per meter - per worker	**0%**
Pessimistic	**0.164**	hours per meter - per worker	**21%**

Roofing

Storeroom roofs consist of a central layer of 10 cm diameter cana de guayaquil bound to a perpendicular layer of 3 cm cana brava with totora twine (Figure 2-2). Fabricating the roof as a series of panels on the ground is the simplest method. Each bay of the storeroom requires two panels, erected pairs with one section on each side of the gable tied together at the ridgeline. A mixture of grass and mud is applied once the panels are secured.

There are no data available concerning the construction of this type of roof. The individual estimator, using judgement and experience, conceptualizes the process and establishes a reasonable rate. In this case, the estimate is that two cana workers can fabricate one panel up to 2.5 m by 3 m, in an 8-hour day (Table 2-11). Further, the two workers can erect and plaster four panels per day (Table 2-12).

Table 2-11: Productivity - Fabricate roof panels.

Crew Size	2 Cana Workers		
Productivity Range			%
Optimistic	12.80	hours per panel	-20%
Most Likely	16.00	hours per panel	0%
Pessimistic	19.20	hours per panel	20%

Table 2-12: Productivity - Erect roof panels.

Crew Size	2 Cana Workers		
Productivity Range			%
Optimistic	3.20	hours per panel	-20%
Most Likely	4.00	hours per panel	0%
Pessimistic	4.80	hours per panel	20%

Project Estimate

The project estimate (Table 2-13) is the result of combining the installed quantities with the *most likely* unit rates, on a per-activity basis according to the WBS. An analysis of the data reveals several important facts:

- The total estimate for the storeroom is 1,184 labor hours.
- Construction of the adobe shell is by far the most expensive component, with manufacturing, transporting, and installation of adobes representing the majority of the labor. The roof is a relatively minor portion of the project.
- The distance material is transported to the site has a sizeable impact on the overall cost. Transportation costs of adobe and cana alone represent more than 30% of the total project cost.

Based upon this information, a contractor would attempt to keep the hauling distance to a minimum, and concentrate management attention to the adobe-related activities. Regarding the overall confidence level of the estimate, there is solid productivity data for the adobe manufacturing, transporting, and installation, the primary consumers of labor. Since data was not available to estimate accurately the fabrication and erection of the roof panels, there is the temptation to perform an experiment to establish accurate rates. However, these activities have only a slight impact on the project, and unless the unit rates are potentially under or overestimated by a vast margin, data gained from a field experiment would do little to improve the overall accuracy of the estimate. The same situation exists with hand plastering for similar reasons. This estimate review is ideally suited as a means of determining the impact of weak or missing data as well as determining the direction of future research designs.

The data also reveal an opportunity to simplify the estimate without losing accuracy by incorporating the clay floor estimate into the plastering activity. The activities are similar in nature and their unit rates are essentially the same. The schedule logic developed in the next section helps determine whether they can be combined.

The project estimate is a static measure of the labor required to construct the project. By itself, the estimate provides a means of comparing the relative labor investment between individual structures or sites. However, quantifying the labor investment is only a partial use of the data since construction is a dynamic activity. The process of modeling the dynamics of the construction process follows.

Table 2-13: Project estimate.

Activity No.	Item Description	Estimated Quantity		Unit Rates		TOTAL Labor Hours	Percent of Total Project
		A	x	B	=	C	
Adobe Shell							
S-A-01	Manufacture Adobes	40.2	m^3	7.0	hrs/m^3	280	24%
S-A-02	Transport Adobes	40.2	m^3	7.8	hrs/m^3	315	27%
S-A-03	Erect adobe walls	40.2	m^3	9.9	hrs/m^3	396	33%
S-A-04	Plaster adobe walls	64.2	m^2	0.83	hrs/m^2	53	5%
S-A-05	Install clay floor	4.5	m^2	0.95	hrs/m^2	4	0.4%
	Subtotal - Labor Estimate for Adobe Shell					1,049	89%
Roof							
S-R-01	Procure & Transport Cana Brava	1800	m	0.0262	hrs/m	47	4%
S-R-02	Procure & Transport Cana de Guayaquil	60	m	0.1353	hrs/m	8	1%
S-R-03	Fabricate roof panels	4	ea.	16.0	hrs/ea.	64	5%
S-R-04	Erect roof panels	4	ea.	4.00	hrs/ea.	16	1%
	Subtotal - Labor Estimate for Roof					135	11%
	Total Labor Hours for Storeroom					**1,184**	

Scheduling

Eight discrete activities represent all of the work involved in constructing the storeroom, and the project estimate summarizes the number of labor hours for each. The next step is to develop the *project schedule.* The project schedule represents the construction work plan showing how the activities relate to one another in the construction sequence, and using the length of time required for each activity, calculates the total length of the project.

Logic Diagrams

Each of the activities represents a separate yet interdependent task. A *logic diagram*, or network, is a graphical method used to define how each activity relates to every other activity, and is the basis for the project schedule. Development of the logic diagram proceeds systematically on an activity by activity basis to sequence the work.

In the *Precedence Diagramming Method* (PDM), boxes represent activities and arrows the logical relationships. Each activity is analyzed in terms of which activities must be completed before it can begin (predecessors), and which activities must wait until it is complete (successors). A milestone is an activity that represents a significant point in time to indicate the occurrence of an event such as the start or end of a set of related activities. Milestones have no duration or impact on the duration of the schedule.

Figure 2-10 is a simple logic diagram for the storeroom. This example shows that once the project starts, procurement of cana and manufacturing of the adobes can begin. Fabrication of the roof panels cannot start until both the cana guayaquil and can brava are on-site. In this case, the procurement of cana activities are the predecessors of the roof fabrication and erecting the roof panels is the successor. Similarly, erecting the adobe walls cannot begin until the adobes have been manufactured and transported to the site. Once the walls are in place, there is no technical reason that erecting the roof panels, plastering the walls, and placement of the floor can all begin since none of these activities are dependent upon the other. The basic logical relationship used for the activities is *Finish to Start* (FS), which states that the predecessor activities must finish before the successors can begin.

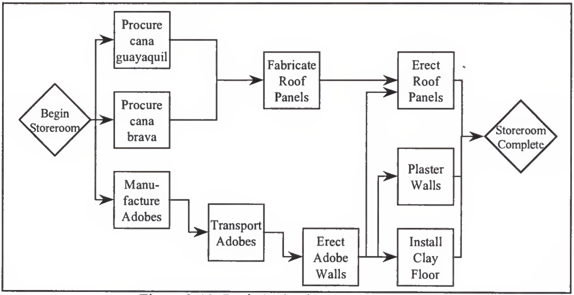


Figure 2-10: Basic logic diagram for storeroom.

While this project is small and manageable, a large network with hundreds or thousands of activities becomes complicated quickly. With the basic logic complete, it is important to evaluate and review the network in terms of simplification and site conditions. For example, procurement and transportation of cana to the job-site and fabrication of the roof panels could be merged into a single activity and still maintain the integrity of the logic. These activities all occur in the same timeframe, probably by the same workers, and consolidation simplifies the network (Figure 2-11). Similarly, as noted earlier, installing the clay floor is an insignificant part of the project, and combining it into the plastering activity serves to simplify the network with no loss of estimate accuracy or logic integrity. Consequently, the estimated labor hours for cana procurement are rolled into the roof fabrication estimate, and clay flooring into plastering.

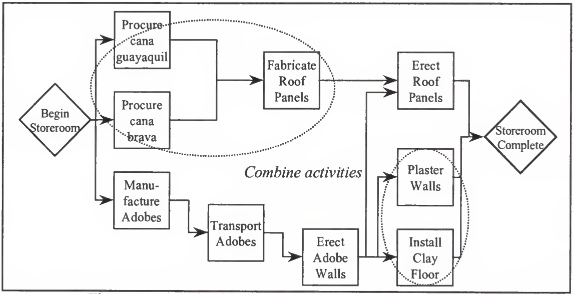


Figure 2-11: Logic diagram - consolidating the storeroom logic.

The logic diagram initially consists mainly of inflexible relationships called *absolute logic.* These relationships are unambiguous and are often the result of simple physics i.e., installing the roof panels must occur after erecting the walls. There are however, many instances where a softer type of *preferential logic* is useful for tailoring the logic to reflect the project plan. For instance, in the initial logic for the storeroom, erecting the roof panels and plastering the walls can take place concurrently. While technically possible, based upon experience, a better work plan may be to allow the adobe workers to complete the shell of the storeroom, including the wall plastering, before the roof installation begins. This allows the adobe workers to complete their portion of the project without having to work around the roofing installation, resulting in a smoother work operation. Note that this change does not violate the absolute logic; the network still requires the roof installations to follow erection of the walls. The judicious and creative use of preferential logic allows a scheduler to accurately reproduce various project plans and alternatives. Figure 2-12 illustrates the result of consolidating activities and use of preferential logic.

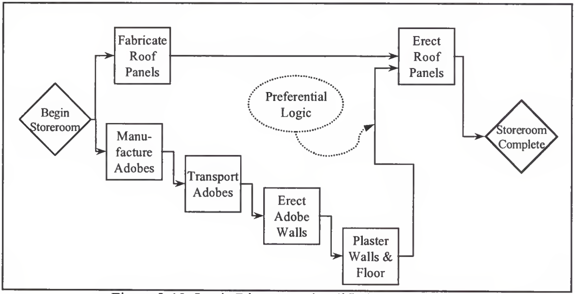


Figure 2-12: Logic Diagram - simplified storeroom logic

Activity Durations

The length of time required to complete an activity, the *duration,* is a function of the estimated labor hours, crew sizes, and the length of the workday. This example assumes an 8-hour workday. Table 2-14 is the revised project estimate showing the changes made by consolidating activities, and adding data concerning crew sizes and duration calculations.

An activity's duration is determined by dividing the total number of workers, times the hours in a workday, into the total labor hours. For example, it takes 8.75 workdays, for a crew of four workers to manufacture the adobes. Rounding durations up to the nearest whole day builds in a slight cushion to each activity since the number of available hours is slightly more than the hours required.

Reducing the duration of an activity involves increasing the number of crews assigned. However, simply adding workers to a crew or assigning additional crews has practical limits. For instance, it takes two workers to fabricate a roof panel. Attempting to shorten the fabrication time by adding a third person to the crew would not necessarily improve the productivity proportionately since three workers is more than can effectively work together. In this case, it is more effective to add an additional crew of two workers to fabricate a separate panel. The object is to balance the crew assignments within a desired timeframe to meet the goals of the project. As shown later, selective addition of crews can shorten the length of the project, provided the additional workers are available.

Table 2-14: Revised project estimate.

Activity No.	Item Description	Estimated Quantity	Unit Rates	TOTAL Labor Hours	Crew Size	No. of Crews	Total No. of Workers	Activity Duration (Days)*
		A x	B =	C	D x	E	F	G = C/(F*8)
Adobe Shell								
S-A-01	Manufacture Adobes	40.2 m^3	7.0 hrs/m^3	280	4	1	4	9
S-A-02	Transport Adobes	40.2 m^3	7.8 hrs/m^3	315	1	4	4	10
S-A-03	Erect adobe walls	40.2 m^3	9.9 hrs/m^3	396	4	1	4	13
S-A-04	Plaster adobe walls & floor	68.7 m^2	0.83 hrs/m^2	57	2	2	4	2
	Subtotal - Labor Estimate for Adobe Shell			1,049				
Roof								
S-R-03	Fabricate roof panels	4 ea.	29.8 hrs/ea.	119	2	1	2	8
S-R-04	Erect roof panels	4 ea.	4.00 hrs/ea.	16	2	1	2	1
	Subtotal - Labor Estimate for Roof			135				
	Total Labor Hours for Storeroom			1,184	* one day = 8 hours, rounded up to the nearest whole day.			

Critical Path Method

The Critical Path Method of scheduling (CPM) is a network-based modeling system used to simulate the time and resource aspects of a project. A CPM schedule calculates the times activities can start and finish, their resource requirements, and the overall duration of the project. CPM permits evaluation and manipulation of the project plan in terms of lengths of time and efficient resource utilization by integrating activity data from the project estimate with the relationships from the logic diagram. The calculations produce several sets of dates and other information:

- Early Start (ES) - The earliest date an activity can begin, providing all predecessor activities are complete.
- Late Start (LS) - The latest date an activity can begin without delaying the project end date.
- Early Finish (EF) - The earliest date an activity can finish.
- Late Finish (LF) - The latest date an activity can be completed without delaying the project end date.
- Total Float (TF) - The amount of time an activity can be delayed before delaying the end date of the project. It is the difference between the early dates and late dates of an activity.
- Critical Path - The collection of activities that have the least amount of Total Float, usually zero. It is the longest path through the network and represents the earliest possible project end date.

Figure 2-13 shows the results of combining the logic developed in Figure 2-12, and the duration data in Table 2-14, presented in a time-scaled logic diagram. Here each

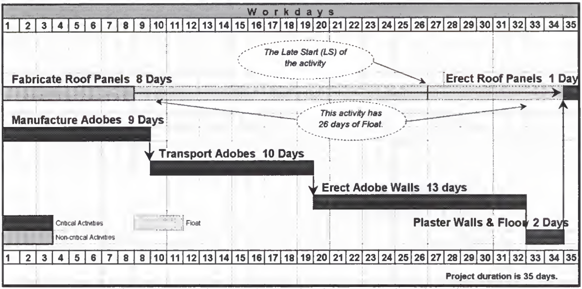


Figure 2-13: Time-scaled logic diagram, early schedule.

bar represents an activity's duration as well as its relationship to the other activities. The manufacture, transport, erection, and plastering of the adobes all proceed sequentially with the fabrication of the roof panels occurring concurrently. According to the logic, all of these activities must be complete before the final activity, Erect Roof Panels, can begin. The critical path for the storeroom consists of the activities Manufacture Adobes, Transport Adobes, Erect Adobe Walls, Plaster Adobe Walls and Floors, and Erect Roof Panels. They make up the longest path through the network, have no float, and represent the earliest time the project can finish, which is thirty-five days. A delay in any of these activities results in a delay to the project end date. The awareness and management of the activities on the critical path is vital to the on-time completion of the project. The activity Fabricate Roof Panels is eight days in duration with twenty-six days of float. That is, this activity may begin as early as day one of the project (ES) or as late as day twenty-seven (LS) without delaying the start of the Erect Roof Panels activity. This difference in the early and late date represents its Total Float of twenty-six days. In effect, this eight-day activity can happen anytime in a span of thirty-four days. Float creates flexibility in the schedule and presents opportunities to manage resources more effectively. A schedule using the early start and finish dates is called the *Early Schedule.* Conversely, using the late starts and finishes yields the *Late Schedule.*

Resource Distribution

The schedule produced in Figure 2-13 assumes that all the required resources are available. Next, the schedule is *resource loaded* to determine the resource requirements or labor distribution of the project. Assigning the number of workers estimated for each activity generates the histogram shown in Figure 2-14. In this case, the resources are assigned by types of workers. It shows a range of two to six workers needed to build the project according to the early schedule. Four adobe workers work from day 1 to day 34 of the project, with the two cana workers required at the beginning and the end.

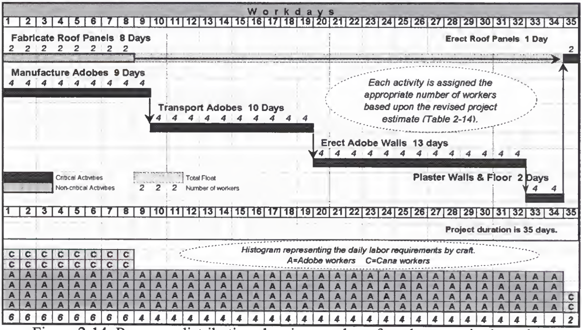
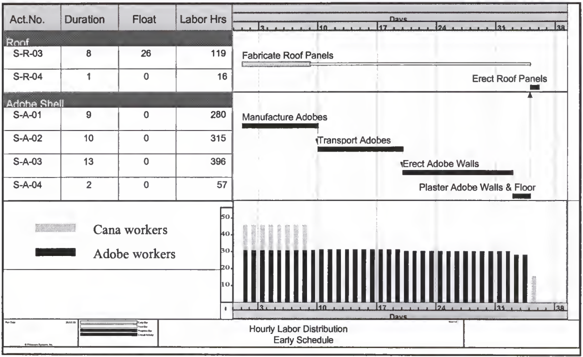


Figure 2-14: Resource distribution showing number of workers required per day.

A more accurate accounting of resources comes by loading the schedule with the estimated hours, rather than workers for each activity. Figure 2-15 shows a computerized version[2] of the schedule, with the hourly resource estimates by type of workers, on a daily basis.



Act.No.	Duration	Float	Labor Hrs
Roof			
S-R-03	8	26	119
S-R-04	1	0	16
Adobe Shell			
S-A-01	9	0	280
S-A-02	10	0	315
S-A-03	13	0	396
S-A-04	2	0	57

Figure 2-15: Labor distribution in hours per day.

The schedules developed in this section are the result of basic scheduling and resource allocation techniques. The following section describes advanced procedures of managing resources, developing complex logic, and finally, a statistical method to quantify the uncertainty in the data.

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[2] Primavera Project Planner, Version 2.0. Copyright 1996, Primavera Systems, Inc. Under license to the M.E. Rinker Sr. School of Building Construction, University of Florida.

Advanced Scheduling Techniques

Resource Constrained Scheduling

The schedules generated to this point assume that all the labor resources needed for all activities are available. However, this is not always the case. Often resources are limited, in which case the schedule must be adjusted to work within the existing resource availability. For example, the schedule shown in Figures 2-14 and 2-15 requires a maximum of six workers, four for adobe work and two for cana. If only four workers are available, the original schedule is not feasible due to the lack of labor resources. A *resource-constrained* schedule compares the resource requirements to the resource availability and makes the necessary adjustments to level and optimize resource usage and minimize the impact to the schedule. One solution, (Figure 2-16) shows the impact of the limited resources by scheduling the cana activities until after the adobe work is complete. Consequently, the new project duration is forty-three days, as compared to the original thirty-five days.

An examination of the resource-constrained schedule indicates that the cana activities use only two of the four available workers. A review of the project estimate (Table 2-14) shows only one crew of cana workers assigned to the activity. In this instance, adding a second crew of two workers to fabricate roof panels decreases the activity's duration from eight days to four days, and reduces the project duration from forty-three days to thirty-nine days (Figure 2-17).

Projects may be resource constrained on individual resources such as adobe workers or cana workers, combinations of resources, or on total resources.

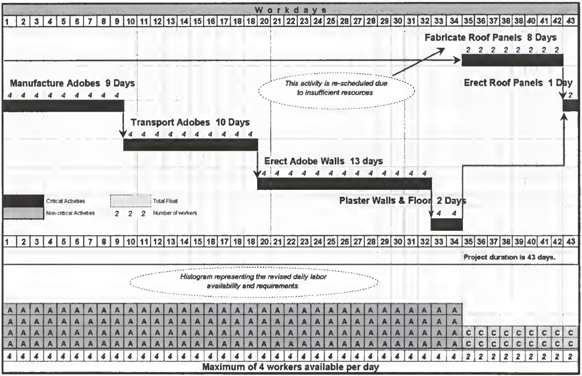
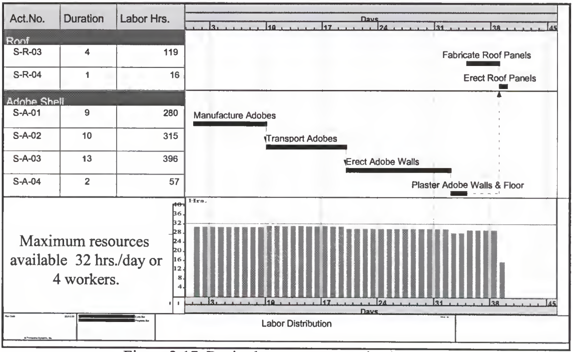


Figure 2-16: Simple resource constrained schedule.



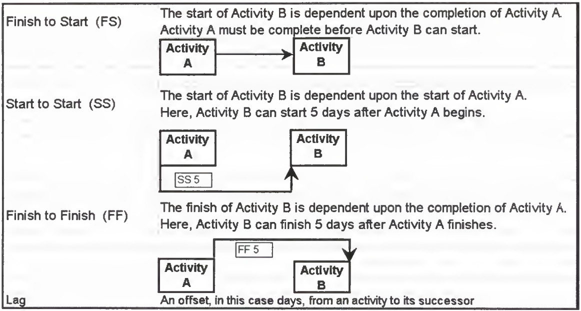
Act.No.	Duration	Labor Hrs.
Roof		
S-R-03	4	119
S-R-04	1	16
Adobe Shell		
S-A-01	9	280
S-A-02	10	315
S-A-03	13	396
S-A-04	2	57

Maximum resources available 32 hrs./day or 4 workers.

Figure 2-17: Revised resource constrained schedule.

Complex Logic

The networks up until now use the logical relationship *finish to start* (FS) where the predecessor activities must finish before the successors can begin. While simplicity is a virtue in scheduling, there are instances where additional logical relationships assist in modeling the construction plan more accurately (Figure 2-18).



Finish to Start (FS)

The start of Activity B is dependent upon the completion of Activity A. Activity A must be complete before Activity B can start.

Start to Start (SS)

The start of Activity B is dependent upon the start of Activity A. Here, Activity B can start 5 days after Activity A begins.

Finish to Finish (FF)

The finish of Activity B is dependent upon the completion of Activity A. Here, Activity B can finish 5 days after Activity A finishes.

Lag

An offset, in this case days, from an activity to its successor

Figure 2-18: Complex logical relationships.

For example, the current logic indicates that transportation of the adobes cannot begin until all adobe manufacturing is complete. However, it was previously determined that at Chan Chan, adobes are ready to transport after an initial curing period of five to seven days. Therefore, transporting adobes can actually begin five to seven days after the start of adobe manufacturing, say seven days to be conservative. Correspondingly, transportation cannot finish until at least seven days after the last adobes are made. In scheduling terms, manufacturing adobes controls both the start and finish of transporting adobes in a start to start (SS) and finish to finish (FF) relationship with a lag of seven days as shown in Figure 2-19.

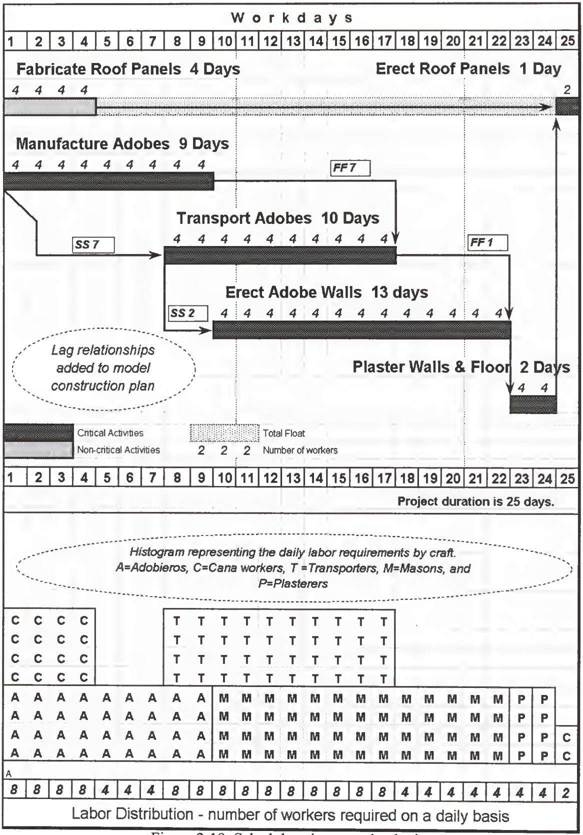


Figure 2-19: Schedule using complex logic.

Similarly, there is no need to wait until all the adobes are on site before starting construction of the wall, but all of the adobes must be delivered at least one day before the masons complete the shell. A *start to start 2* relationship between transportation and installation essentially gives the adobe transporters a two-day head start before the masons begin erecting the wall, and a *finish to finish 1* insures the adobes are delivered on time.

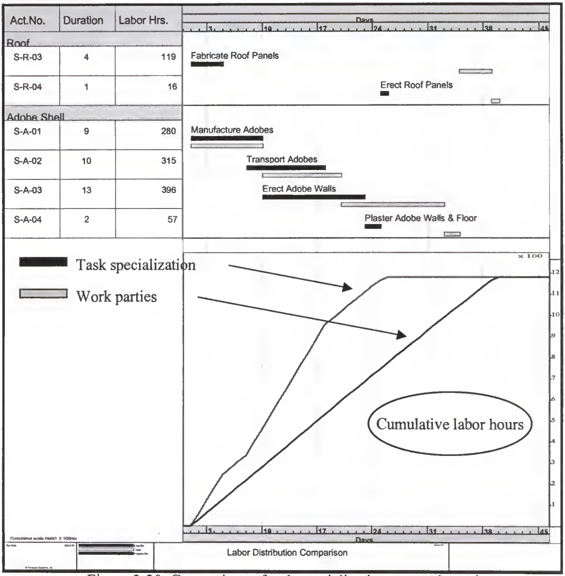
Technically the plastering work could overlap the construction of the adobe shell as long as the plasterers do not outpace the masons. This might be a viable option on a larger structure with a significant amount of plastering, or under a strict time constraint. However, for this project the duration of the plastering activity is only two days, so the standard finish to start relationship maintains simplicity.

This construction plan yields an aggressive yet practical schedule that produces the shortest duration of the project, twenty-five days, provided that all required resources are available when needed. Using lag relationships and complex logic offers several advantages when analyzing the possible construction times of the storeroom under various labor organizational theories. The histogram in Figure 2-19 shows that this approach lends itself well to the *task differentiation* model, where specialized crews perform the work. While the total number of workers varies, the crew sizes and number of workers within each crew is uniform. The same logic also effectively models the labor theory of individual *work parties* being responsible for all phases on construction, by leveling the resources as done in Figure 2-17. In fact, this complex logic yields identical results to that in Figure 2-17 when similarly resource constrained. In each instance, the total labor hours required to construct the storeroom are the same, only their distribution changes. This final revision to the logic results in a realistic and flexible network capable of modeling both labor organization theories.

Target Schedules

Target schedules are a means of storing schedules for later comparison. In contemporary applications, they serve two primary purposes. During actual construction a target schedule is often a copy of the original schedule, which when compared to the actual progress of the work, facilitates performance measurement. In the pre-construction phase, target schedules permit the comparison of multiple construction strategies in terms of time and resource utilization. This ability to compare alternative construction strategies is a valuable planning tool in construction project management and when applied in an archaeological context is the primary means of representing the results of alternate labor organization theories.

Using the network logic shown in Figure 2-19, Figure 2-20 illustrates the comparison of activity timings and labor distributions between the two labor organization theories. The top portion shows two bars for each activity. The top bar represents when the activities occur in the task specialization model with unlimited resource availability, while the bottom bar represents the work party theory constrained by a maximum of four workers. The cumulative curves correspond to the resource usage of each model. Using target schedules, the differences of time and resource usage is apparent for each theory. Each model uses the same amount of labor but the distribution is very different. The task specialization model completes the project in the shortest practical time of twenty-five days, but consumes resources quickly. The work party model takes thirty-nine days but uses resources at a constant rate.



Act.No.	Duration	Labor Hrs.
Roof		
S-R-03	4	119
S-R-04	1	16
Adobe Shell		
S-A-01	9	280
S-A-02	10	315
S-A-03	13	396
S-A-04	2	57

Figure 2-20: Comparison of task specialization vs. work parties.

Probabilistic Scheduling

The estimated project duration is twenty-five days with an unlimited labor supply, or thirty-nine days with a group of four workers. However, CPM scheduling is deterministic and uses a single estimate and duration derived from the *most likely* unit rates. By presuming there is no uncertainty in productivity, it does not account for variability. Nevertheless, uncertainty in productivity does exist since it is impossible to make precise correlations when estimating prehistoric construction. This uncertainty is represented by the *optimistic, pessimistic*, and *most likely* range of unit rates calculated for each activity, and the effect of this uncertainty on the project's estimate and schedule is quantifiable in terms of probabilities.

Statistical sampling programs such as Monte Carlo[3] combined with CPM schedules simulate numerous project outcomes based upon the full range of productivity rates. Table 2-15 shows the project estimate expanded to include the full range of unit rates previously developed. These rates then translate to the estimated labor hours and durations by activity. For instance, the deterministic values for manufacturing adobes, which were the basis for the CPM schedules, are 280 labor hours over a nine-day duration. However, this activity could optimistically take as few as 210 labor hours over a seven-day duration, or as many as 300 labor hours over a ten-day duration.

To determine the probable project cost and durations, the full range of values are factored into the schedule shown in Figure 2-19, then simulated using Monte Carlo sampling for 1000 cycles. Each simulation cycle randomly samples durations across a triangular distribution defined by the *optimistic, most likely*, and *pessimistic* durations for each activity. Beginning with the *optimistic* value, a continuous distribution is assumed where the probability increases along a straight line to the *most likely* value, then decreases to *pessimistic* (Figure 2-21). Frequency distribution histograms and cumulative probability curves plot the results.

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[3] Monte Carlo 3.0k for Primavera. Copyright 1996, Primavera Systems, Inc. Under license to the M.E. Rinker Sr. School of Building Construction, University of Florida.

Table 2-15: Project estimate with probabilistic data.

Activity No.	Item Description	Estimated Quantity		Unit Rates		TOTAL Labor Hours	Crew Size	No. of Crews	Total No. of Workers	Activity Duration (Days)*		
										OPTIMISTIC	MOST LIKELY	PESSIMISTIC
		A	x	B	=	C	D	x E	F	G = C/(F*8)	G = C/(F*8)	G = C/(F*8)
Adobe Shell												
				5.2	hrs/m³	210			4	7		
S-A-01	Manufacture Adobes	40.2	m³	7.0	hrs/m³	290	4	1	4		9	
				7.5	hrs/m³	300			4			10
				6.7	hrs/m³	269			4	9		
S-A-02	Transport Adobes	40.2	m³	7.8	hrs/m³	315	1	4	4		10	
				9.0	hrs/m³	363			4			12
				8.7	hrs/m³	350			4	11		
S-A-03	Erect adobe walls	40.2	m³	9.9	hrs/m³	396	4	1	4		13	
				11.0	hrs/m³	442			4			14
				0.57	hrs/m²	39			4	2		
S-A-04	Plaster adobe walls & floor	68.7	m²	0.83	hrs/m²	57	2	2	4		2	
				0.98	hrs/m²	67			4			3
Roof												
				23.9	hrs/ea.	95			4	3		
S-R-03	Fabricate roof panels	4	ea.	29.8	hrs/ea.	119	2	2	4		4	
				36.5	hrs/ea.	146			4			5
				3.2	hrs/ea.	13			2	1		
S-R-04	Erect roof panels	4	ea.	4.0	hrs/ea.	16	2	1	2		1	
				4.8	hrs/ea.	19			2			2
										* one day = 8 hours, rounded up to the nearest whole day		
Estimate Totals				Optimistic		976	labor hours					
				Most Likely		1,184	labor hours					
				Pessimistic		1,337	labor hours					

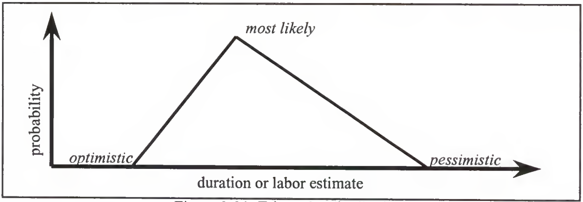

Figure 2-21: Triangular distribution.

From a labor cost perspective, the task specialization and work party theories are equivalent since they use the same unit rates. Figure 2-22 shows there is a 69% probability of completing the project in 1184 labor hours, the deterministic value, with a mean of 1165 labor hours. Correspondingly, there is a 95% probability the project will require 1230 labor hours or less. Taking into account all the uncertainties regarding weak or missing data, there is a 95% probability that the original estimate of 1184 hours is accurate to ± 6.25%.

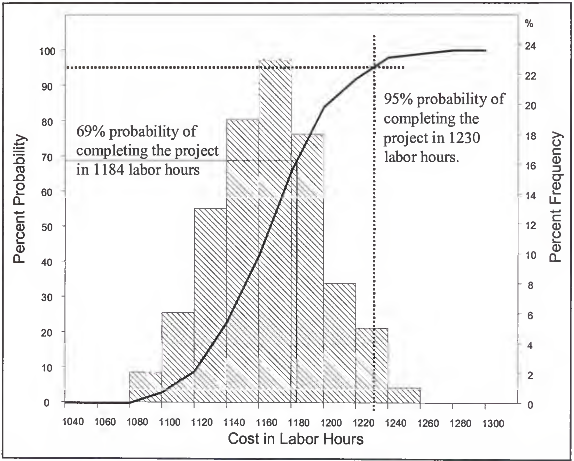

Figure 2-22: Cost probability graph.

In terms of the overall project length, Figure 2-23 shows the duration probability for the task specialization model. The simulated project durations range from 24 to 28 days, with a mean of 25.35 days. There is a 55% probability of completing the project in 25 days, the deterministic value, and a 95% probability that the project will finish in 26 days. Overall, there is a 90% probability that the deterministic schedule duration of 25 days is accurate to ± 1.5 days.

For the work party model (Figure 2-24), the simulated project durations range from 36 to 43 days, with a mean of 39.37 days. There is a 55% probability of completing the project in 39 days, the deterministic value, and a 95% probability that the project will finish in 41 days. There is a 90% probability that the deterministic schedule duration of 39 days is accurate to ± 2 days.

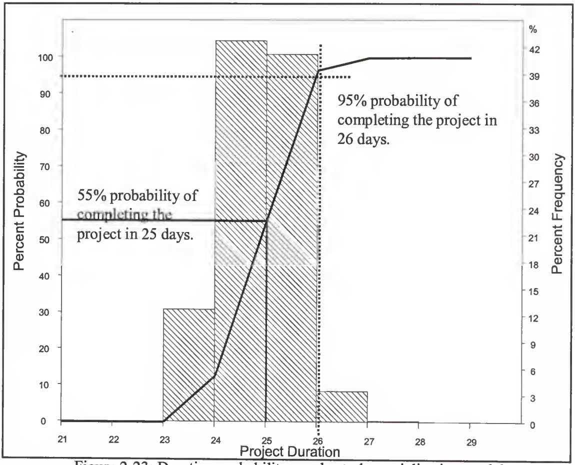

Figure 2-23: Duration probability graph - task specialization model.

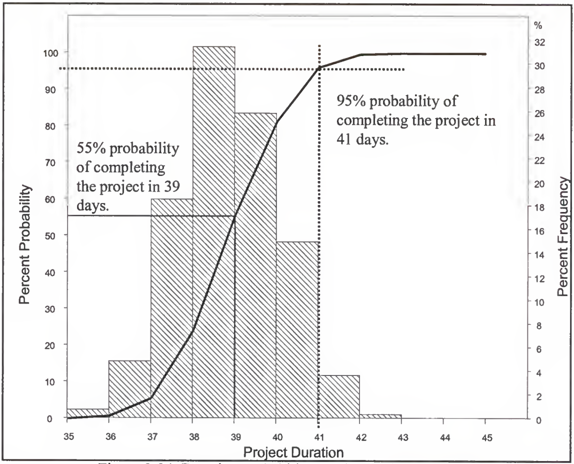

Figure 2-24: Duration probability graph - work party model.

Summary

The Monte Carlo simulations show that it is possible to quantify both the labor investment and construction time of complex architecture under multiple labor organizational theories, with a high degree of accuracy.

For archaeologists, this methodology represents a standardized, reproducible process for determining single-site expenditures of time and labor as well as comparisons among and between sites. Additionally, this procedure is flexible enough to assess the time and cost parameters even when there is missing or variable data, and assist in determining which, if any, field experiments are required. New data are readily accepted, and alternate work plans and theories are straightforwardly tested.

To recap, the process of calculating the labor investment represented in a project requires:

1. Defining the Scope of Work, and breaking the project down into manageable pieces using a Work Breakdown Structure.
2. Performing a Quantity Survey to determine the types and amounts of installed materials.
3. Identifying and estimating productivity in the form of unit rates.
4. Calculating the Project Estimate from the installed quantities and unit rates.

Estimating the overall duration of a project involves:

1. Preparing Logic Diagrams to represent the project work plan(s).
2. Establishing crew sizes and activity durations.
3. Calculating a CPM schedule based on the logic and resource requirements.
4. Comparing target schedules to quantify differences in work plans.
5. Performing risk analyses to account for uncertainty.

The next chapter applies this methodology to quantifying the time and cost parameters of Ciudadela Rivero.

CHAPTER 3
CIUDADELA RIVERO

Introduction

This chapter applies the methodology outlined in the previous chapter to analyze Ciudadela Rivero in terms of labor hours and construction time. It consists of a general architectural description of the features and elements common to most of the compounds as well as a walk-through narrative of Ciudadela Rivero. Next is the definition of the scope of work contained in this case study followed by a discussion of construction techniques and unit rates for construction of the components not detailed in the previous chapter. A section is devoted to producing a detailed labor estimate for both the original configuration of the compound and the adobe wall addition. Finally, possible time-frames for construction of the ciudadela is established by project simulations reflecting and comparing an unlimited/unrestricted resource model to versions representing the kin-based work parties, and task specialization labor organization theories.

Overview of Ciudadela Rivero

General description of major features

The compound making up the existing configuration of Ciudadela Rivero measures approximately 185 meters wide by 380 meters long surrounded by massive walls up to 9 meters high (Figure 3-1 & 3-2). These massive enclosure walls taper from 4 meters at the base to 1 meter at the top. On the north, east, and west sides, an outer adobe wall and inner tapia wall run parallel separated by a 3 to 4-meter wide corridor (Figure 3-3). On the south end, the exterior adobe walls turn the corner and abut the tapia wall. On the north end, the inner tapia wall ends abruptly leaving a 95-meter gap (Figure 3-4). It is probable that the original configuration of the compound consisted of a single tapia wall enclosure with a full-length tapia wall on the north end (Figure 3-5). The connection between the massive adobe wall and tapia wall on the south end, and the abutments of interior walls against the east and west tapia walls suggest that the inner tapia wall is the earlier of the two. It appears that a later remodeling effort demolished a portion of the north tapia wall and added a more elaborate entryway and the outer massive adobe walls.

The tripartite division of the compound consists of a northern sector, central sector, and southern sector or conchone (Figure 3-5). All of the interior walls and structures are made of adobe and covered with a mud plaster. The primary structures within the compound are courts, storerooms, audiencias, walk-in wells, and a burial complex.

Due to severe wear from erosion and looting, the ruins are in relatively poor condition. No walls or structures remain at their original height with the majority only a meter or two high. The massive walls survive relatively intact with the exception of areas where erosion has caused a structural failure. Size estimates of the original walls vary from up to 3 meters high and 1 meter thick in the storeroom and audiencia complexes, to over 4 meters high and 1.5 to 2 meters thick around larger structures such as courtyards and the burial complex. Note that the descriptions to follow represent the condition of the ciudadela as it might have been when originally constructed. Day (1973) presents a detailed accounting of the existing ruins.

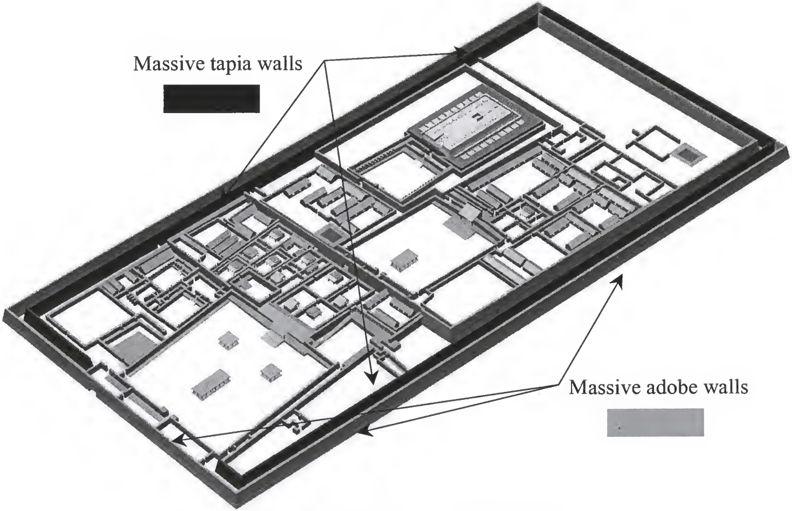

Figure 3-1: Existing configuration of Ciudadela Rivero

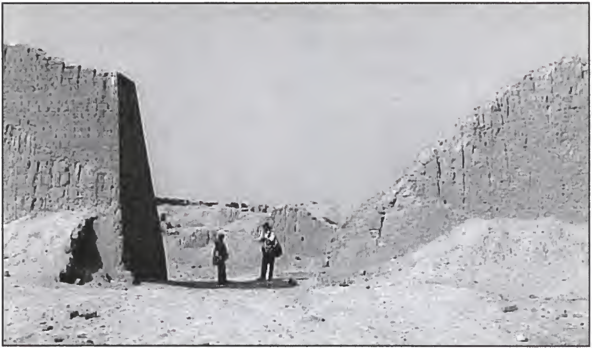

Figure 3-2: North entrance looking through the massive adobe walls into the compound.

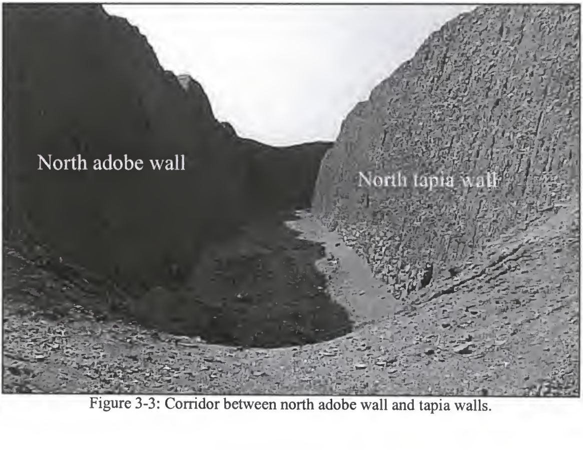

Figure 3-3: Corridor between north adobe wall and tapia walls.

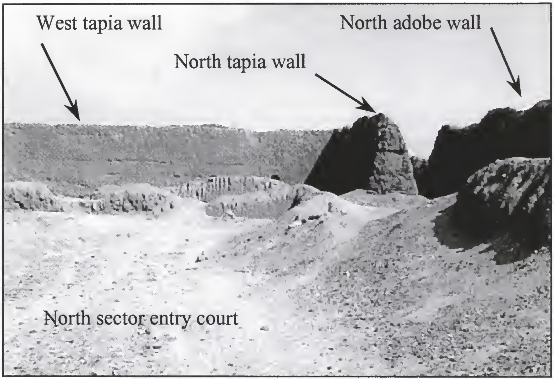

Figure 3-4: View of gap in north tapia wall

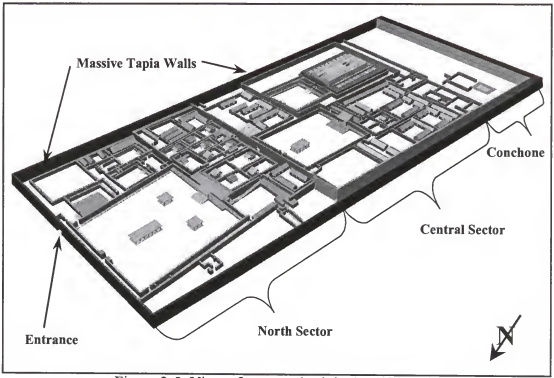

Figure 3-5: View of proposed original configuration

Open courts of various sizes generally have larger walls, over 4 meters tall, and raised benches along the walls with one bench serving as the *stage* for ritual ceremonies (Figures 3-6 & 3-7). Benches are often filled with rubble or broken adobes and faced with plaster or cobbles. Ramps lead from the floor of the court to the center of the stage. In the larger courts, archaeological evidence in the form of postmolds from wooden columns of algorrobo and pieces of cana strongly suggest that at least part of theses stage areas had roofs.

Gabled storerooms, built in clusters, occur throughout the north and central sectors. The walls are generally 1 to 1.5 meters thick, and contain predominantly two to five bays (Figures 3-8 & 3-9). The interior of each bay is 1 to 2 meters square with up to a 1-meter high threshold. The roof is cana brava and guayaquil with a mud plaster cap as discussed previously.

Audiencias are u-shaped structures used primarily for more intimate rituals than the lager courts (Figures 3-10 & 3-11). Each audiencia is situated in its own private court and is relatively consistent in size. The overall dimensions are 4.5 meters by 5.5 meters, with the three walls roughly 1.5 meters thick and 2 to 3 meters high. There are two niches in the interior of each wall. Wood columns of algorrobo embedded into the walls support the cana roof. Due to the advanced stage of erosion, it is impossible to determine the extent of decoration of the audiencias at Ciudadela Rivero. However, audiencias at other compounds do contain friezes in maritime and other motifs, although none remain at or near their original height.

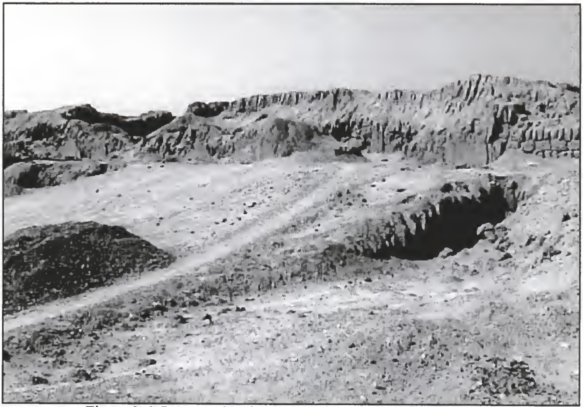

Figure 3-6: Ramp and main platform of north sector entry court.

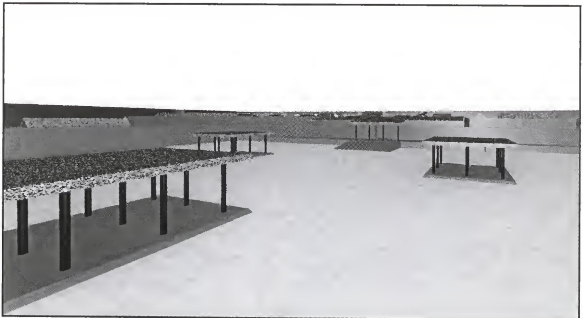

Figure 3-7: View of north sector entry court in virtual model.

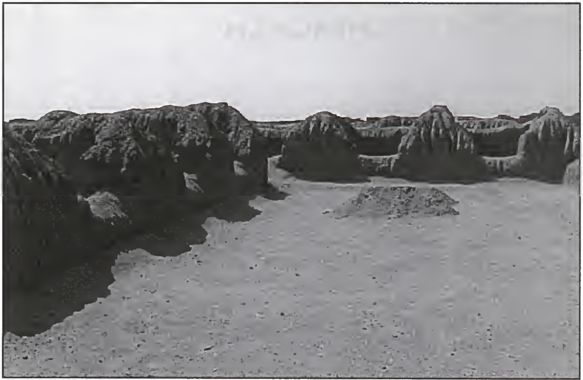

Figure 3-8: Storeroom complex behind west forecourt.

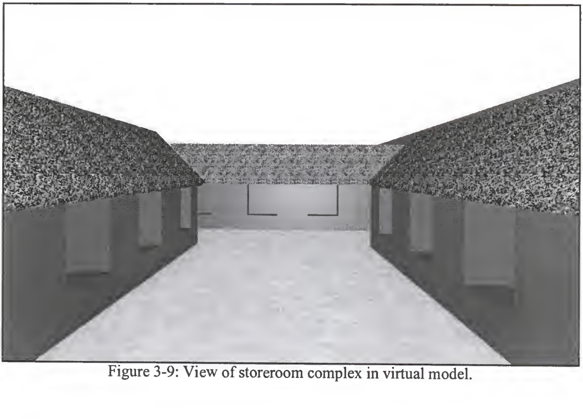

Figure 3-9: View of storeroom complex in virtual model.

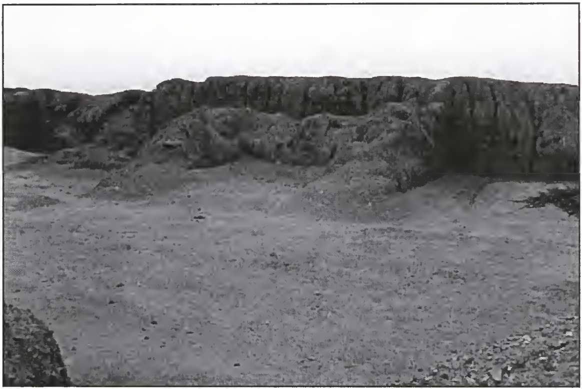

Figure 3-10: Typical ruins of an audiencia.

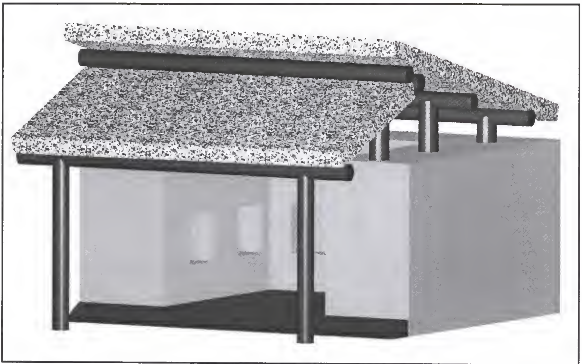

Figure 3-11: Hypothetical view of audiencia.

Set in an extremely arid desert, Chan Chan has an acute lack of surface water. However, an aquifer runs beneath the gravel bed underlying the site. Large walk-in wells dug down to the groundwater provided the source of water for the inhabitants (Figure 3-12). There is a walk-in well in the conchone as well as the central sector.

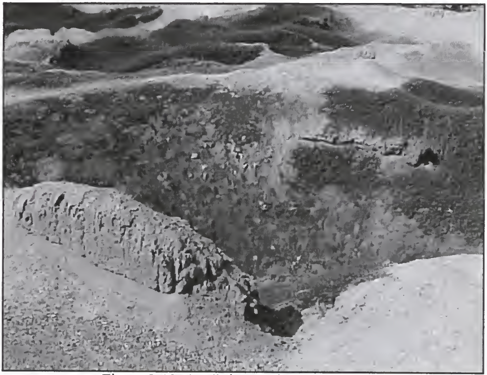

Figure 3-12: Walk-in well in central sector.

The damage from looters and erosion to the burial complex, including the forecourt and burial mound, is extreme to the point that its original composition is an educated guess at best (Figures 3-13 & 3-14). In the most general terms, the burial mound is nearly 50 meters wide, 60 meters long, and consists of an inner tapia core 20 meters wide and 45 meters long, rising to about 8 to 10 meters in height. An adobe structure upwards of 4 meters high surrounds the tapia core on three sides. The honeycombed structures contain numerous burial chambers. A possible u-shaped structure is at the uppermost level.

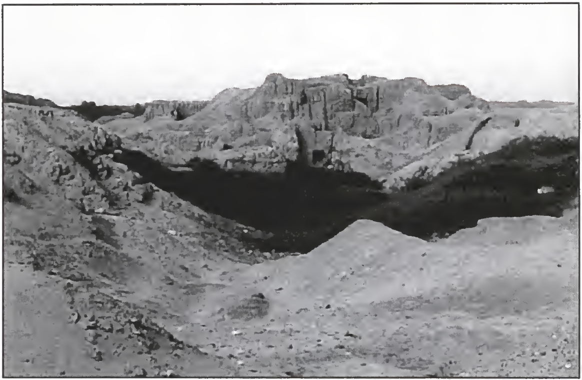

Figure 3-13: View looking south across burial forecourt to burial mound.

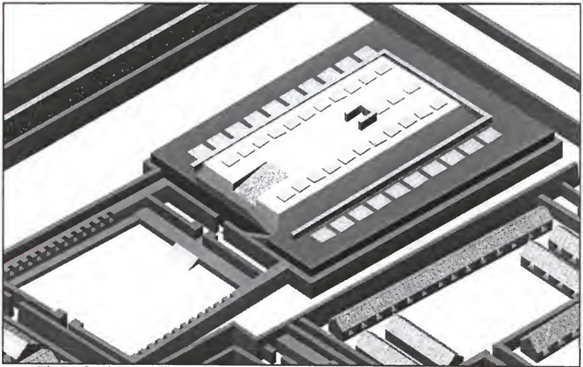

Figure 3-14: Hypothetical view of burial mound and forecourt in virtual model.

Walk-through of the compound

The *main entrance* into the compound is on the north side of the outer wall in the northern sector (Figure 3-15). This entryway leads to the *north sector entry court* approximately 75 meters wide and 80 meters long, surrounded by adobe walls 4 meters high and over 1.5 meters thick. Raised adobe benches a little over 3 meters wide and 1 meter high are along the east, west, and south walls of the court. A ramp rises from the floor of the court to the center of the bench on the south wall. Three groups of postmolds near the center of the court suggest the presence of colonnades.

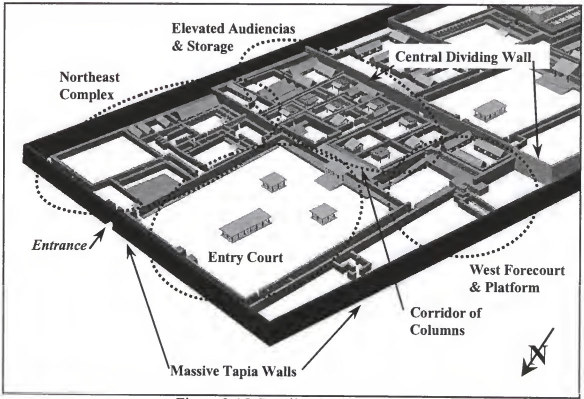

Figure 3-15: Details of north sector.

To the east of the north sector is the *northeast complex* containing a possible kitchen area, three open courts, and a complex of four storage structures. Moving about through this sector as with the rest of the ciudadela is by means of ramps and series of narrow labyrinth-like corridors that serve to control and restrict access (Figure 3-16).

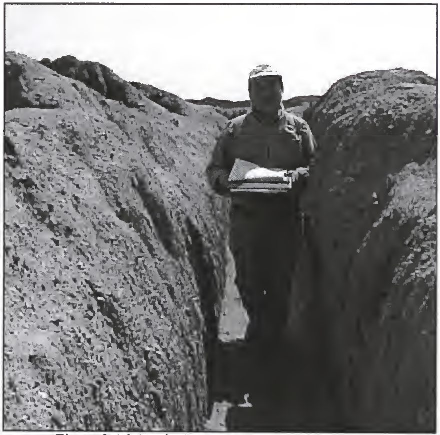

Figure 3-16: Typical narrow corridor in north sector.

The ramp at the south end of the north sector entry court rises three meters and leads to the *corridor of columns*. Following this roofed corridor to the west leads to the *west forecourt* with its ramps and platforms, and storage units to the rear. Taking the corridor of columns to the east leads to the *elevated audiencia and storage complex* containing two groups of audiencias, an open court, and several groups of storage buildings.

An 8 to 9-meter high adobe *central dividing wall* running generally east-west separates the north and central sectors (Figures 3-17 & 3-18). The wall continues south paralleling the west tapia wall through the central sector into the conchone before turning east, again paralleling the south tapia wall.

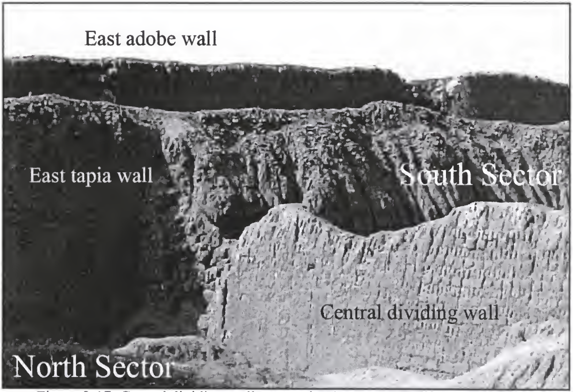

Figure 3-17: Central dividing wall connection between north and central sector.

An entryway through the central dividing wall leads from the north to the central sector. The *east storage complex,* located in the northeast corner of the central sector, contains numerous storage structures and a walk-in well. The *central sector entry court* is 50 meters wide and 85 meters long surrounded by 4-meter high walls. Evidence of postmolds suggests a colonnade similar to those in the north sector entry court. The ramp at the southern end of the entry court leads to an east-west corridor. Access to an elevated terraced platform and a single audiencia court is directly south off this corridor.

Following the corridor to the west leads to the *west storage complex* consisting of five groups of storage units. To the south of the west storage complex is a series of smaller *auxiliary structures*. Taking the corridor to the east leads to the burial complex forecourt that is roughly 35 meters wide and 40 meters long surrounded by 4-meter high walls lined with niches. A set of switchback ramps directly to the south of the forecourt provides access to the burial mound.

The conchone is mostly empty space. It contains ruins of only a few discernable walls, a walk-in well, and may have contained less permanent structures for maintenance and/or service workers.

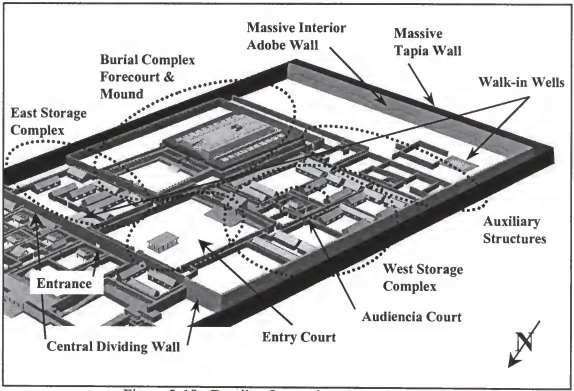

Figure 3-18: Details of central sector and conchone.

Scope of Work

Introduction

The analyses to follow take the approach that the existing layout of Ciudadela Rivero is the result of at least two major construction episodes. The abutments of the adobe walls into the tapia walls, the lack of any transition of the shortened north tapia walls into the final structure, and the fact that no other ciudadela had twin perimeter walls strongly suggests that originally, only a single tapia wall surrounded the ciudadela (Figure 3-5). The existing layout is the result of a later remodeling effort involving the demolition of a portion of the north tapia wall, a rework of the north entry corridor, and the addition of the massive adobe outer wall (Figure 3-1). Therefore, there are two projects, each requiring a scope of work. Specifically *excluded* from both scopes of work are any structures not within the confines of the compound including the annexes on the north and east sides.

It is possible and even probable that remodeling occurred in other areas of the compound, however there is no compelling data that allows any further demarcation between original and remodeled areas. This research assumes that the balance of the work within the ciudadela is as it was originally constructed.

Original Configuration

Specifically included in the scope of work for the original configuration is the general excavation at the site and the procurement, manufacturing, transportation, and installation of all materials in all structures within and including the massive tapia walls. Figure 3-19 represents the first three levels of the WBS for this project. Appendices A and B list the entire WBS's in tabular format.

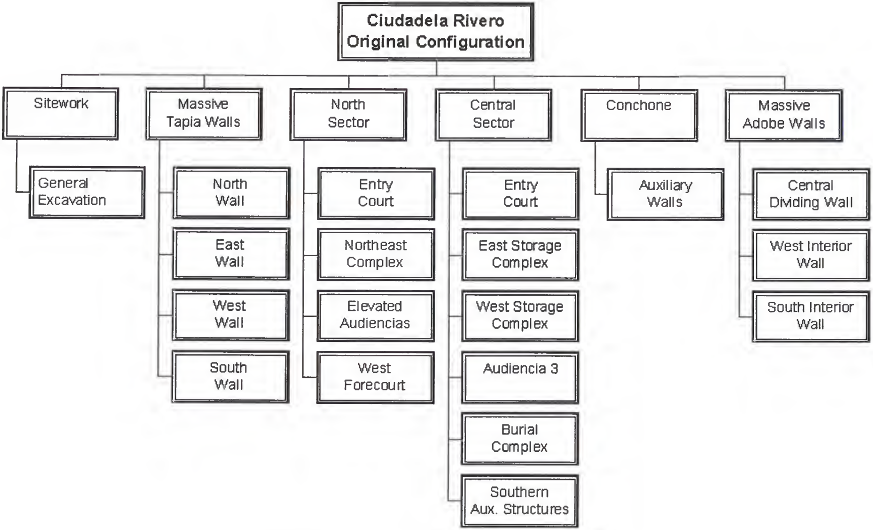

Figure 3-19 Work Breakdown Structure for initial construction episode.

Final Configuration

Specifically included in the scope of work for the final configuration is the addition of the massive adobe perimeter walls. This involves the demolition of the north tapia wall, and the procurement, manufacturing, transportation, and installation of all materials in the walls and benches in the north court entry corridor and the massive adobe walls (Figure 3-20).

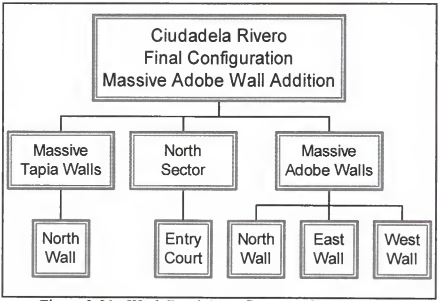

Figure 3-20: Work Breakdown Structure for remodeling.

Estimating

Quantity Survey

Aided by plan maps (Mackey & Moseley: 1974) and a detailed architectural survey of the compound (Day: 1973), field research was conducted at Chan Chan in May, 2000 to photograph, measure, and analyze the ruins of Ciudadela Rivero from a construction perspective. Data from these sources were used to create a 3-dimensional virtual model of Ciudadela Rivero[1].

This architecturally *intelligent* model associates sizes, material types, and quantities for each detailed component of the compound. While it is possible to perform the quantity survey manually, the model allowed the installed quantities of each component to be extracted directly from the model and input into the quantity survey according to the WBS. Table 3-1 presents the quantity information in summary form while the complete detailed quantity survey for each is contained in Appendices C and D.

Table 3-1: Summary of quantity survey.

	Volume of Adobes	Number of Adobes	Volume of Tapia	Area of Plaster
Original Configuration				
Massive interior adobe walls	11,110	1,910,920		9,895
North Sector walls & structures	13,346	2,295,512		25,877
Central Sector walls & structures	9,686	1,665,992		22,194
Conchone walls	230	39,560		456
Burial Mound	14,334	2,465,448	9,180	9,551
Tapia Walls			24,840	20,400
Totals for Original Configuration	48,706 CM	8,377,432 EA	34,020 CM	88,373 SM
Massive Adobe Wall Addition	17,680 CM	3,040,960 EA		21,370 SM

Productivity - Unit Rates

Hand excavation

Chan Chan sits on a desert plain bounded by the Andes Mountains on the east and the Pacific Ocean on the west. The building area of the ciudadelas is a series of wide flat terraces clearly indicating that the Chimu leveled the site. According to modern topographical maps (Mackey & Moseley 1974), the land surrounding Chan Chan slopes towards the ocean at a rate between 2 and 8 meters per 1000 meters, along a line running generally north-south through Ciudadela Rivero. There is no guarantee that the slope was the same at the time of the Chimu, however it is certain that the slope was at least in the same direction.

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[1] MicroStation Triforma® Version 07.01.01.41 Copyright 2000, Bentley Systems, Inc. Exton, PA. Software provided as a grant for this research.

While there is no doubt that the site required leveling, estimating the amount of material excavated to do this requires two assumptions. The first is that the builders moved the minimum amount of material possible. The second is that the excavated soil was used to build the tapia walls directly from the material on the site thus realizing a significant saving of time and labor compared to building adobe walls. The alternative is to excavate and remove the excess material from the site, then turn around and bring it back again to build the walls. The minimum quantity of excavation is equal to the amount of earth necessary to build the massive tapia walls, elevated audiencias, and the burial mound (Figure 3-21). This is the equivalent of removing a little less than 0.6 meters from the entire area of the ciudadela. However, since the goal is to level the site, excavating a wedge shaped section 1.16 meters high at the north end tapering off towards the south produces the required result, which corresponds favorably to the modern slope. The estimate splits the excavation between the north sector, and the central sector and conchone.

The excavation operation consists of digging the soil, and transporting it near its ultimate destination in either the walls or platforms. Conservatively, all areas using the excavated soil are no more than 150 meters from the source of the excavation. Combining the excavation unit rates with the transportation formula used earlier yields a composite unit rate for all excavation and transportation of soil on the site (Table 3-2). Additionally, demolishing the central portion of the north tapia wall during the massive adobe wall addition uses this unit rate.

Volume of earth required:			
Tapia walls	24,840	CM	
Elevated audiencia	7,035		
Burial mound	9,180		
Total fill	41,055	CM	
Minimum excavation required:			
North Sector	27,370	CM	(2/3 of total excavation)
Central Sector & Conchone	13,685		(1/3 of total excavation)
	41,055	CM	
Area of compound	70,300	SM	(185m X 380m)

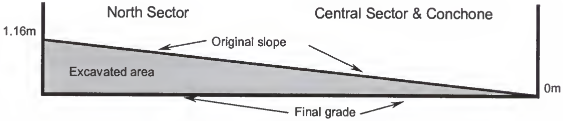

Figure 3-21: Estimated excavation quantities.

Massive tapia walls

A single massive adobe brick wall, 9 to 10 meters high, surrounds each of the compounds at Chan Chan, with the exception of Ciudadela Rivero. Originally, a single massive tapia wall, a form of molded-in-place adobe, enclosed Rivero. A continuous cobble foundation roughly 4 meters wide and 1 meter high provides the base (Figure 3-22). The walls are battered and consist of segments of varying cross sections, molded into blocks 1 to 2 meters high and 2 to 3 meters long in a series of horizontal layers

(Figures 3-23, 3-24, & 3-25). The blocks are molded in place since moving the sections would break them due to their low tensile strength.

Table 3-2: Productivity - Excavation

Source	No. of Workers	Hours Worked	Total Hours	Total Volume		Unit Rate	
Erasmus (wood tools)	1	5	5	2.60	m^3	1.92	hours/m^3
RS Means	1	1.5	1.5	0.76	m^3	1.96	hours/m^3
Walker	1	1.75	1.75	0.76	m^3	2.29	hours/m^3

Recap: Hand Excavation			
Crew Size	1	Laborer	
Productivity Range			
Optimistic	1.9	hours per cubic meter per worker	-2%
Most Likely	2.0	hours per cubic meter per worker	0%
Pessimistic	2.3	hours per cubic meter per worker	17%

(Erasmus 1965: 285; Means 1998: 48; Walker 1947: 55)

Transport Soil - 150 meters			
Crew Size	1	Laborer	
Productivity Range			
Optimistic	3.0	hours per cubic meter - per worker	-25%
Most Likely (avg)	4.0	hours per cubic meter - per worker	0%
Pessimistic	5.0	hours per cubic meter - per worker	25%

Composite Rate: Excavate & Transport Soil - 150 meters			
Crew Size	1	Laborer	
Productivity Range			
Optimistic	4.9	hours per cubic meter - per worker	-17%
Most Likely (avg)	6.0	hours per cubic meter - per worker	0%
Pessimistic	7.3	hours per cubic meter - per worker	22%

There are two methods used to produce an earth wall the size of this size, rammed earth, and direct molding. Both share two distinct advantages over adobe brick. The soil can be much coarser than in adobe bricks, requiring less sorting, and the soil mixture is stiff, requiring significantly less water. In addition, since the earth in the walls is the same earth as the surrounding area, it is feasible that the earth excavated from leveling the site went directly into the construction of the tapia walls.

The rammed earth method uses a slightly moist soil mixture compacted between formwork to create a monolithic wall. Wood forms attached or braced to the already-built sections of wall are filled with soil in layers, and compacted manually with rams or clubs. After each section is complete, the crew moves the form to the next section and repeats the process. However, using formwork leaves distinctive notches and marks on the blocks that are not evident at the site. Further, formwork works well with rectangular sections but the trapezoidal and triangular cross-sections of the walls argue against this method. Finally, the time invested in building, setting, aligning, stripping and resetting forms is usually greater than the time spent transporting and compacting the earth (Easton 1996: 105), thus negating the advantage gained by using the surrounding material.

Direct molding is a method used successfully to create massive earth walls over 8 meters high in other parts of the world (Norton 1997: 36). Earth is delivered to the wall in a plastic state, piled, shaped, and compacted by hand without the use of forms. The soil mixture requires less water than adobe bricks but more than the rammed earth technique. Earth is moistened in pits and worked by hand or feet then carried directly to the wall. Workers either hand or toss lumps of earth to the mason who throws the mixture into the wall section with force. The mason compacts and shapes a series of lumps by hand filling gaps and removing air pockets until the section is complete. Workers stand on the previous layer to install the next level, thus requiring little or no scaffolding.

The trapezoidal and triangular cross sections serve two purposes, to allow the sections to hydrate rapidly, and to provide a form for the interior sections. As with adobe bricks, the tapia sections must dry before they produce any compressive strength so limiting the height and width of each section reduces drying time. In addition, building in sections across the width of the wall provides a ready-made form for the interior component (Figure 3-26). Generally, wall building starts in the corners working up and out using vertical cana poles at regular intervals to insure the correct alignment of the walls.

Providing the materials are at hand, a crew of five workers can mix and place 3.75 cubic meters of tapia per day for a wall up to 3 meters high in a completely manual operation (Table 3-3). However, the placement of tapia at higher elevations requires additional work and the unit rates appropriately adjusted. While the mason may experience a small loss in productivity due to working on and around already-built blocks, the greatest expense is transporting the earth the additional distance to its destination in the wall. Workers must carry the earth up and across previously built sections or up ladders on the side of the wall. Estimated in terms of productivity, placing a section of tapia three to six meters high might require the *equivalent* of two extra workers to carry the tapia the increased distance, or a 40% increase in labor costs (Table 3-4). Similarly, a section six to nine meters high might require the equivalent of four extra workers representing an 80% increase. Due to the physical size of the wall, there is a limit to the number of workers walking on the wall or up ladders so it is not always possible to increase crew size. Basing the unit rates on a per-worker basis offers the flexibility of assigning varying crew sizes while maintaining the proper productivity rate.

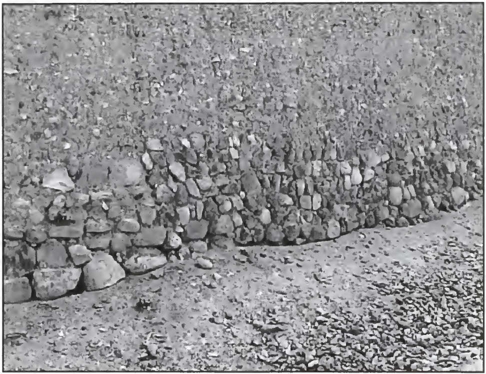

Figure 3-22: Cobble foundation of tapia walls.

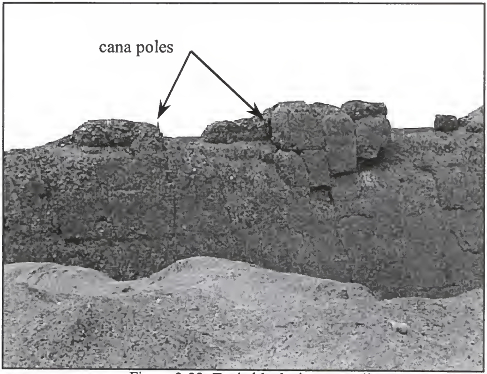

Figure 3-23: Tapia blocks in east wall.

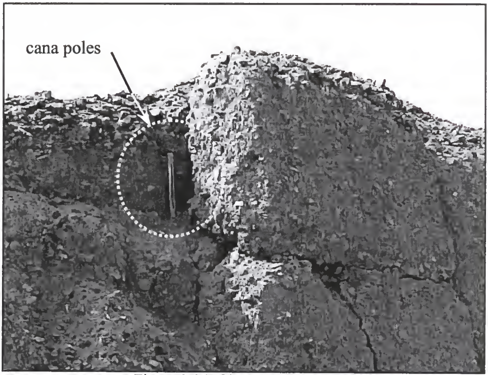

Figure 3-24: Close-up of tapia block.

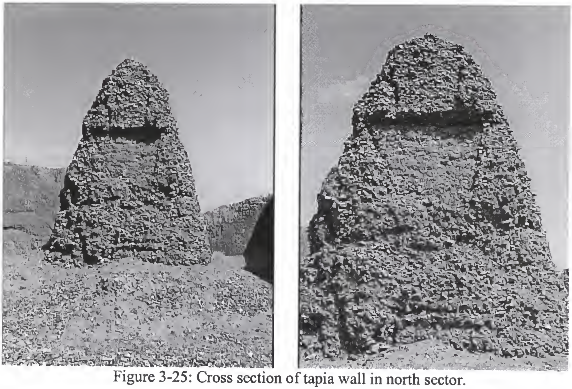

Figure 3-25: Cross section of tapia wall in north sector.

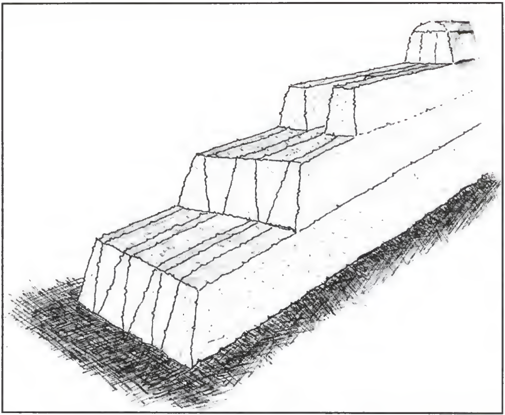

Figure 3-26: Tapia wall construction

Table 3-3: Productivity - Tapia construction 0-3 meters.

Source	No. of Workers	Hours Worked	Total Hours	Volume of Adobes Installed	Unit Rate
Norton	5	8	40	3.75 m^3	10.67 hrs/m^3

Recap: Tapia Installation			
Crew Size	**4**	**Masons**	
Productivity Range			**%**
Optimistic	**8.5**	hours per cubic meter per worker	**-20%**
Most Likely (Average)	**10.7**	hours per cubic meter per worker	**0%**
Pessimistic	**12.8**	hours per cubic meter per worker	**20%**

(Norton 1997: 37)

Table 3-4: Productivity - Tapia construction over 3 meters.

Tapia Installation 3 - 6 meters			
Crew Size	5	**Masons**	
Productivity Range			**%**
Optimistic	**11.9**	hours per cubic meter per worker	**-20%**
Most Likely (Average)	**14.9**	hours per cubic meter per worker	**0%**
Pessimistic	**17.9**	hours per cubic meter per worker	**20%**

Tapia Installation 6 - 9 meters			
Crew Size	5	**Masons**	
Productivity Range			**%**
Optimistic	**15.4**	hours per cubic meter per worker	**-20%**
Most Likely (Average)	**19.2**	hours per cubic meter per worker	**0%**
Pessimistic	**23.0**	hours per cubic meter per worker	**20%**

Massive adobe walls

Adobe walls greater than 3 meters high and up to 4 meters wide occur on the interior of the compound, such as the central dividing wall, the walls surrounding the main courts, and the massive 9-meter walls added after the initial construction. The construction techniques are similar with a few variations on the massive exterior walls.

The massive exterior walls are initially laid out on the ground and built in a series of courses. Work starts on the corner leads with intermittent rack-back leads down the length of the wall (Figure 3-27). Work continues in a step-like manner filling in the voids between the leads. At elevations over three meters, cana poles set vertically establish the centerline of the walls to assure proper alignment (Figure 3-28). Workers line up the wall visually by sighting down the line of poles. As work progresses upward, workers stand on the previously placed course and work backwards. Final closure at the topmost course requires ladders to pass material to the masons.

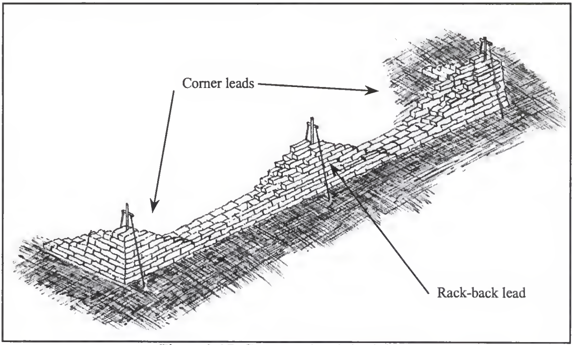

Figure 3-27: Corner and rack-back leads.

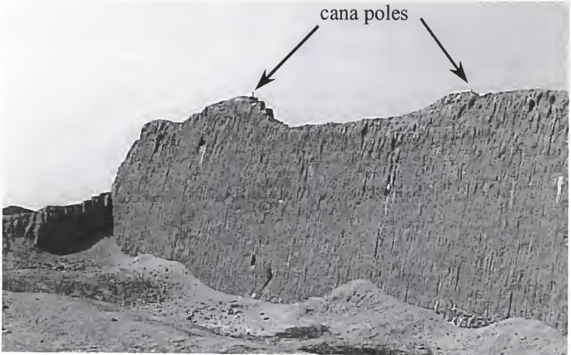

Figure 3-28: Massive adobe wall showing alignment poles.

To maintain the vertical batter of the wall, two methods work well. The first, suggested in the Chan Chan Museum (Figure 3-29), indicates the attachment of a "T" to the top of the cana poles, with twine leading vertically down from the "T" to the base to delineate the taper. The mason sights down these vertical leads or connects horizontal stringlines between the vertical lines as a guide. While technically possible, this configuration is physically fragile and, based on the 10 to 20 meter spacing of the poles, requires the maintenance of long string lines.

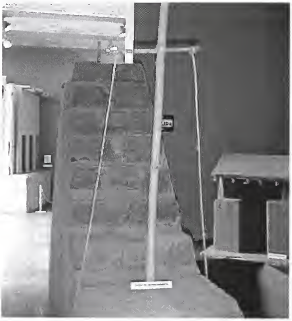

Figure 3-29: Vertical taper controls as proposed in the Chan Chan Museum, Trujillo, Peru.

An alternative method eliminates the requirement of string lines and requires less-skilled workers. In this application vertical cana poles used as *speed leads* are attached to or leaned against the corners and work areas and set to the proper angle with a plumb bob to define the taper of the wall (Figure 3-30). A single skilled mason sets the leads for the next section of work and the workers fill-in the areas between the leads. The ten meter high adobe walls of the Convento in Espanola, New Mexico used such speed leads during construction in the 1990's (Figure 3-31; Wilson pers. comm). Using construction techniques virtually unchanged from the time of the Chimu, the masons used no scaffolding, preferring to work from the completed portions of the wall and ladders.

The unit rates previously calculated for adobe wall construction are not sufficient to account for walls over three meters high and require adjustment. As with the construction of tapia walls, a loss of productivity occurs as the height increases, primarily do to the additional transportation of the adobes. For heights between three and six meters, the equivalent of two additional workers to the crew size reflect this decreased productivity, with four additional workers being added for heights between six and nine meters (Table 3-5).

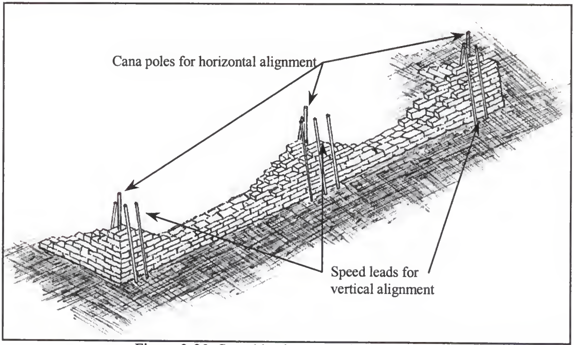
Cana poles for horizontal alignment
Speed leads for vertical alignment

Figure 3-30: Speed leads on massive adobe wall.

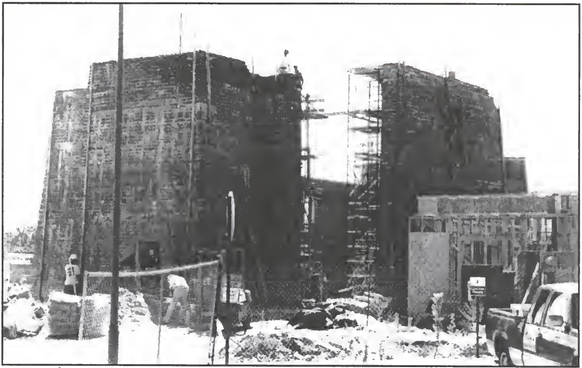

Figure 3-31: Speed leads in use at the Convento in Espanola, New Mexico. (Photo courtesy of Quentin Wilson)

Table 3-5: Productivity - Adobe construction over 3 meters.

Adobe Installation 3 - 6 meters			
Crew Size	5	**Masons**	
Productivity Range			%
Optimistic	12.2	hours per cubic meter per worker	-12%
Most Likely (Average)	13.8	hours per cubic meter per worker	0%
Pessimistic	15.4	hours per cubic meter per worker	12%

Adobe Installation 6 - 9 meters			
Crew Size	5	**Masons**	
Productivity Range			%
Optimistic	15.7	hours per cubic meter per worker	-12%
Most Likely (Average)	17.7	hours per cubic meter per worker	0%
Pessimistic	19.8	hours per cubic meter per worker	12%

Plastering

Applying the mud plaster to the exterior of high walls necessitates using ladders or scaffolding. Generally, plastering begins at the top and works down the face of the wall so as not to damage the work below. Due to the taper of the wall, the scaffolding is not freestanding; it must lean against the wall like a ladder (Figure 3-32 & 3-33). Lightweight scaffolding of cana de guayaquil is easily constructed and reused multiple times by moving it from section to section as work progresses.

The unit rates previously calculated for plastering included a factor of two to account for uncertainty. The rates for plastering high walls are adjusted again by adding the equivalent of one and two workers to the crew for heights 3 to 6 meters and 6 to 9 meters respectively (Table 3-6). This allowance includes ample time to account for both the increased work to build the scaffolding and transport the mud to the higher elevations.

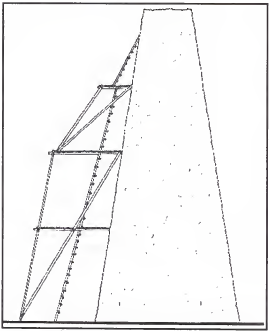

Figure 3-32: Cana scaffolding

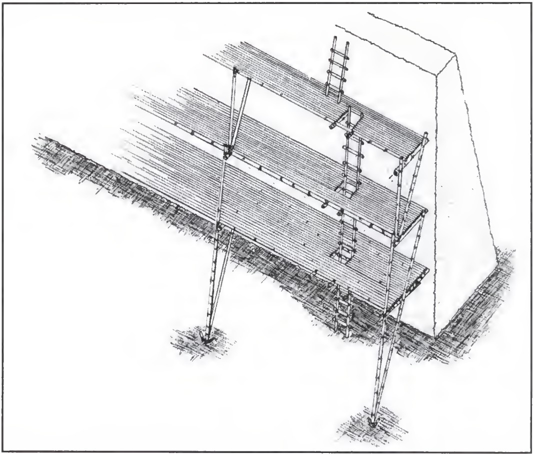

Figure 3-33: Use of cana scaffolding to plaster high walls.

Table 3-6: Productivity - Plastering over 3 meters.

Plaster (Stucco) 3 - 6 meters			
Crew Size	2	Plasterers	
Productivity Range			%
Optimistic	0.86	hours per square meter - per worker	-31%
Most Likely	1.25	hours per square meter - per worker	0%
Pessimistic	1.47	hours per square meter - per worker	18%

Plaster (Stucco) 6 - 9 meters			
Crew Size	2	Plasterers	
Productivity Range			%
Optimistic	1.15	hours per square meter - per worker	-31%
Most Likely	1.66	hours per square meter - per worker	0%
Pessimistic	1.96	hours per square meter - per worker	18%

Harvesting and transporting algorrobo

The colonnades and roofs in the entry courts, and the audiencia roofs use the wood of the algorrobo tree as columns. While the specific location of the source is unknown, the tree still grows in the region within close proximity of the site. For estimating purposes, the assumed distance from the site to the source is 5,000 meters.

Since only a single unit rate relative to manually cutting and harvesting trees is available it is considered the optimistic rate, then factored upwards by 25 and 50 percent for the most likely and pessimistic values (Table 3-7). The transportation and procurement rates combine to yield a composite rate for algorrobo.

Table 3-7: Productivity - Harvesting and transporting algorrobo.

Source	No. of Workers	Hours Worked	Total Hours	Total Length		Unit Rate	
Walker	4	3	12	7.00	m	1.71	hours/m
Includes felling, trimming, cutting, and stacking.							

Recap: Cutting and Trimming Trees

Crew Size	**4**	**Laborers**	
Productivity Range			**%**
Optimistic	**1.71**	hours per meter per worker	**0%**
Most Likely	**2.14**	hours per meter per worker	**25%**
Pessimistic	**2.57**	hours per meter per worker	**50%**
(Walker 1947: 52)			

Recap: Transporting Algorrobo - 5000 meters

Crew Size	**4**	**Laborers**	
Productivity Range			**%**
Optimistic	**0.89**	hours per meter - per worker	**0%**
Most Likely (Average)	**1.11**	hours per meter - per worker	**25%**
Pessimistic	**1.33**	hours per meter - per worker	**50%**

Composite Rate: Procure and Transport Algorrobo - 5000 meters

Crew Size	**4**	**Workers**	
Productivity Range			**%**
Optimistic	**2.60**	hours per meter - per worker	**0%**
Most Likely	**3.25**	hours per meter - per worker	**25%**
Pessimistic	**3.90**	hours per meter - per worker	**50%**

Recap of unit rates

The work breakdown structures and quantity survey identified the work types necessary to estimate the construction of the compound. Table 3-8 recaps the unit rates for these operations. Applying these unit rates to the quantity survey produces the labor estimate for Ciudadela Rivero.

Table 3-8: Productivity - Recap of unit rates to estimate Ciudadela Rivero.

		Labor hours per unit of measure			Crew
Activity	uom	Optimistic	Most Likely	Pessimistic	Size
Hand excavation	CM	4.90	6.00	7.30	1
Excavate walk-in wells	CM	4.90	6.00	7.30	1
Manufacture adobes	CM	5.20	7.00	7.50	5
Transport adobes	CM	6.70	7.80	9.00	1
Erect adobe structures	CM	8.70	9.90	11.00	5
Erect adobe walls 0-3m	CM	8.70	9.90	11.00	5
Erect adobe walls 3-6m	CM	12.20	13.80	15.40	5
Erect adobe walls 6-9m	CM	15.70	17.70	19.80	5
Erect tapia walls 0-3m	CM	8.50	10.70	12.80	5
Erect tapia walls 3-6m	CM	11.90	14.90	17.90	5
Erect tapia walls 6-9m	CM	15.40	19.20	23.00	5
Plaster walls 0-3m	SM	0.57	0.83	0.98	2
Plaster walls 3-6m	SM	0.86	1.25	1.47	2
Plaster walls 6-9m	SM	1.15	1.66	1.96	2
Harvest algorrobo	LM	2.60	3.25	3.90	4
Fabricate roof panels	EA	23.90	29.80	36.50	2
Erect roof panels	EA	3.20	4.00	4.80	2
CM= cubic meters SM= square meters LM=linear meters EA=each					

Estimating

Calculating the estimated labor hours involves applying the estimated unit rates to the quantity survey. The following section calculates the project estimates for the original configuration of the compound and the adobe wall addition. Summary data are shown here while the complete detailed estimates are in Appendices C and D.

Original configuration

Based upon the *most likely* productivity rates, the project estimate for the construction of Ciudadela Rivero in its original configuration is 2.1 million labor hours (Table 3-9). Building the interior walls and structures in the north sector, central sector, and conchone accounts for half of the labor. Constructing the massive outer tapia and inner adobe walls consumes one third, and the balance is in general excavation.

The distribution of labor hours from a work type perspective indicates that manufacturing, transporting, and installing adobes represents two thirds of all work (Figure 3-34). The tapia walls and excavation account for just under a third, with the balance in plastering and cana related activities.

In terms of the uncertainty of the estimate, each unit rate developed consisted of a productivity range represented by *optimistic*, *most likely*, and *pessimistic* values. Appendix E includes a complete listing of all activities and their estimated ranges. Using this range of rates, the uncertainty in productivity is quantified by the Monte Carlo simulation procedure described in the previous chapter. The results (Figure 3-35) show there is an 85% probability of completing the project in 2,123,774[2] hours, the deterministic estimate, with a mean of 2,101,888 hours. Correspondingly, there is a 95% probability the project requires 2,136,000 hours. Taking into account the uncertainty regarding weak or missing data the deterministic estimate is quite accurate, provided the actual productivity was within the ranges reflected in the unit rates.

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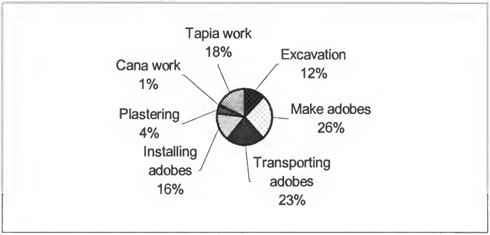
[2] There are minor differences between the labor hours represented in the schedule and the project estimate due to rounding.

Table 3-9: Summary estimate for the original configuration.

Ciudadela Rivero - Original Configuration	
Sitework	
General Excavation	259,290 Labor hrs.
Subtotal- Sitework	259,290 Labor Hrs.
Massive Tapia Walls	
North Wall	56,844 Labor hrs.
East Wall	126,898 Labor hrs.
West Wall	128,625 Labor hrs.
South Wall	56,844 Labor hrs.
Subtotal- Massive Tapia Walls	369,212 Labor Hrs.
North Sector	
Entry Court	70,189 Labor hrs.
Northeast Complex	81,338 Labor hrs.
West Forecourt & Platform	76,351 Labor hrs.
Elevated Audiencias & Storage	155,673 Labor hrs.
Subtotal- North Sector	383,551 Labor Hrs.
Massive Adobe Walls	
Central Dividing Wall	58,620 Labor hrs.
West Interior Wall	156,030 Labor hrs.
South Interior Wall	104,500 Labor hrs.
Subtotal- Massive Adobe Walls	319,149 Labor Hrs.
Central Sector	
Entry Court	60,322 Labor hrs.
West Storage Complex	116,246 Labor hrs.
East Storage Complex	49,426 Labor hrs.
Audiencia Court	13,845 Labor hrs.
Burial Complex	515,440 Labor hrs.
Southern Auxilliary Walls	31,241 Labor hrs.
Subtotal- Central Sector	786,521 Labor Hrs.
Conchone	
Auxilliary Walls	6,059 Labor hrs.
Subtotal- Conchone	6,059 Labor Hrs.
Total Ciudadela Rivero	2,123,782 Labor Hrs.



Excavation	259,290	Plastering	93,609
Making adobes	551,972	Cana work	17,060
Transporting adobes	481,002	Tapia work	379,907
Installing adobes	340,942		

Figure 3-34: Distribution of labor hours by work type for the original configuration.

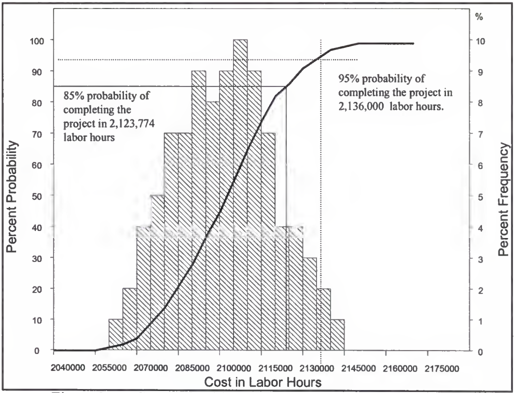


Figure 3-35: Cost probability graph for the original configuration.

While uncertainly in productivity is accounted for, the issue of transportation costs requires a qualification. Transportation of adobes is a major contributor to the estimate accounting for 23% of the total hours. The major factor effecting the transportation estimate is distance, and since the location of the adobe making operation is unknown, the assumption used to develop the unit rate was 250 meters. A substantial deviation in actual distance would produce a marked difference in the estimate.

Finally, the estimated unit rates for cana activities such as harvesting and roofing, and plastering are educated guesses. Although hard estimating data are lacking for these activities, there is no justification for field experiments since their contribution to the total is minor. It would take a major inaccuracy in the existing range of rates to have any material impact on the estimate.

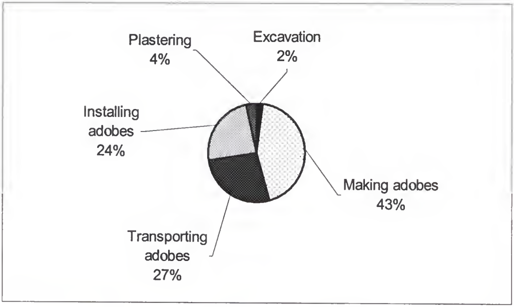
Adobe wall addition

Based upon the *most likely* productivity rates, the project estimate for the addition of the massive adobe walls to the ciudadela is approximately 630,500 labor hours (Table 3-10). The distribution of labor hours from a work type perspective indicates that virtually all the labor involves manufacturing, transporting, and installing adobes (Figure 3-36).

The Monte Carlo simulation quantifies the variability of the estimate using the range of unit rates shown in Appendix F. The results (Figure 3-37) show there is an 89% probability of completing the project in 630,469 hours, the deterministic estimate, with a mean of 623,000 hours. Correspondingly, there is a 95% probability the project requires 633,200 hours.

Table 3-10: Summary estimate for the adobe wall addition.

Ciudadela Rivero - Adobe Wall Addition	
Massive Tapia Walls	
North Wall - Demolition	11,490 Labor Hours
Subtotal- Massive Tapia Walls	11,490 Labor Hours
North Sector	
Entry Court	7,042 Labor Hours
Subtotal- North Sector	7,042 Labor Hours
Massive Adobe Walls	
North Wall	119,310 Labor Hours
East Wall	241,897 Labor Hours
West Wall	250,731 Labor Hours
Subtotal- Massive Adobe Walls	611,938 Labor Hours
Total Adobe Wall Addition	630,469 Labor Hours



Demolition	11,490	Installing adobes	151,424
Making adobes	276,322	Plastering	22,503
Transporting adobes	168,730		

Figure 3-36: Distribution of labor hours by work type for the adobe wall addition.

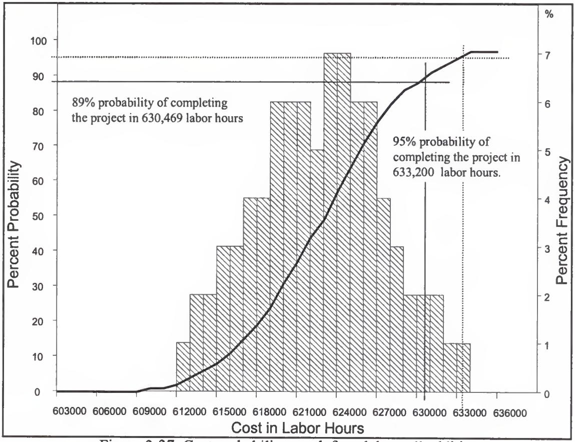


Figure 3-37: Cost probability graph for adobe wall addition.

As in the estimate of the original configuration, transportation of adobes is a major factor for 27% of the total hours. Again, the assumption that the adobe making operation is within 250 meters of the site is essential to the accuracy of the estimate.

Scheduling

Introduction

A project schedule is the representation of a specific construction work plan concerning the sequencing of work and the deployment of resources. This section determines project durations based upon work plans and schedules developed for the original configuration of the compound and the adobe wall addition, and demonstrates the effects the task specialization and work party theories have upon construction time.

Assumptions

Developing viable scheduling alternatives requires certain basic assumptions common to all. As stated previously, the first assumption is that the existing ciudadela is the result of two separate construction episodes. The original configuration consisting of a single massive outer tapia wall, followed later by the massive adobe wall addition.

On one hand, it is technically possible to stretch the construction of the ciudadela over decades using a very small number of workers, or to work in intermittent spurts. On the other, intensifying the effort by using more workers than the optimum can reduce the construction time, although a loss of overall productivity is likely. Each case introduces any number of specific assumptions, and while it is possible to simulate these options, the purpose here is not to test every possibility, but to demonstrate the methodology and establish baselines of how long the project *should* have taken under *normal* circumstances. The approach here assumes each construction episode worked continuously in a diligent and efficient manner.

The length of the workweek is set at five, 8-hour days, or 40 hours per week. Regardless of the actual number of hours worked per week, it is unlikely that the amount of effective work exceeded 40 hours per week (Figure 3-38). The consensus of numerous reports on the effects of scheduled overtime on construction projects concludes:

> Where a work schedule of 60 or more hours per week is continued longer than about two months, the cumulative effect of decreased productivity will cause a delay in the completion date beyond that which could have been realized with the same crew size on a 40-hour week. (Business Roundtable: 1980)

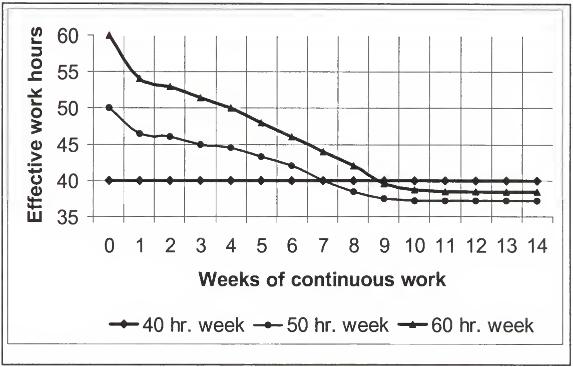


Figure 3-38: The effects of overtime on productivity.

While differences may exist, there are no allowances or adjustments made regarding the relative work efficiency of ancient versus contemporary workers, nor for the use of women or children in the workforce.

As stated previously, the distance of the adobe-making operation from the site is significant since the transportation of adobes is a major contributor to the labor estimate. This fact was certainly not lost on the builders; thus, it is reasonable to assume that the adobe making operation was as close to the site as possible. There is sufficient area within an average 250-meter radius of the ciudadela to supply the raw materials required, including large expanses of *mahamaes* or sunken gardens, and several walk-in wells to the southeast (Figure 3-39).

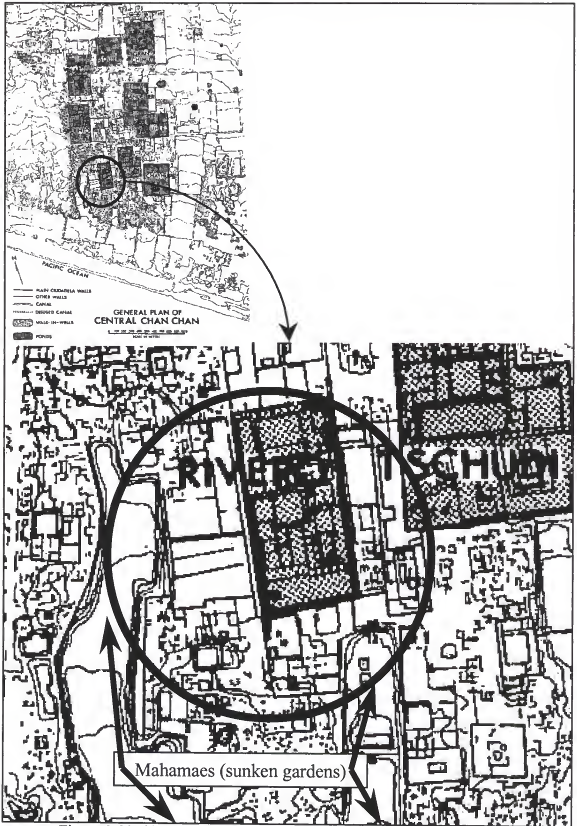


Figure 3-39: Site layout surrounding Ciudadela Rivero. (Moseley 1994)

Original Configuration

Construction work plan

There are numerous possible work plans for constructing the compound. Factors influencing the overall construction plan include the site layout, availability of raw materials, water, housing, and privacy. If Ciudadela Rivero was the last compound built (Kolata 1982:82), or built concurrently with Ciudadela Tschudi (Moseley 1990: 24), the area to the east is unavailable for use (Figure 3-39). Although there is no precise chronology to many of the smaller features, in the site's final state, walk-in wells, and housing in the form of barrios are located to the northwest and southwest of the compound. These areas are equally suitable in terms of sufficient space, raw material, and water to stage the adobe making operations as well as housing for the workers.

The physical layout of the compound is along a north-south axis, and it is logical that construction follows the same plan, moving from north to south (Figure 3-40). Building north to south requires erecting the north, east, and west tapia walls first, leaving the south end open for access. By completing the north sector first, ceremonial functions could take place in the more public areas of the compound while the more private central sector, separated by the central dividing wall, is still under construction. Privacy and restricted access is a characteristic of the architecture at Chan Chan. Closing in all of the compound except the south end provides the most restricted access and privacy even during the construction process. Therefore, the overall construction plan presented here calls for using the area to the south and southwest of the compound for construction operations and housing, and building the interior from north to south.

The first activities on the site involve general excavation to level the site and dig the walk-in wells necessary to provide potable water for workers and to mix tapia and plaster. Once the excavation is sufficiently complete, construction begins on the massive tapia walls. The north, east, and west tapia walls are constructed simultaneously using corner leads at each corner and rack-back leads in the center of the east and west walls. The physical size and space of the wall limits the number of people working on each section. Construction involves building in teams consisting of two crews of five workers each, with one crew on the inside of the wall and the other on the outside. Two teams start at each corner and rack-back lead, and work outward using the excavated material for the tapia.

Once the tapia walls have reached roughly three meters in height, the compound is secure from access and view from the outside, with the exception of the south end. At this point, construction begins on the interior structures in the north sector. Adobes are manufactured in the areas south of the compound then transported through the open south end to their destination, while mud mortar and plaster are mixed on site.

Working space limits the number of workers in any given interior area, and specific crew sizes for each area appear in Appendix C. The general layout of the interior consists of storerooms and audiencia structures enclosed in individual courts or complexes connected by narrow passageways between the walls. The construction strategy for each complex is to build the interior structure(s) first, erecting the enclosing walls, then backing-out to construct the next complex. Building the interior enclosure walls before the structures is technically possible but extremely inefficient and unlikely since it requires the workers and materials to constantly navigate the narrow labyrinth-like corridors.

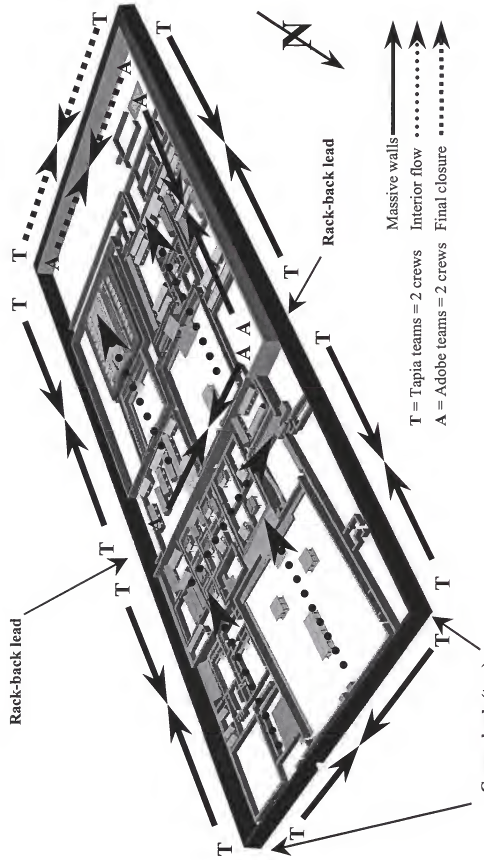


Figure 3-40: Construction work flow.

Staffing the massive adobe central dividing wall and the west adobe wall is similar to the tapia walls, with teams working from the corners to the center. Once the central dividing wall is complete, the north sector is fully functional and secure while work progresses on the balance of the ciudadela.

Work on the central sector flows north to south, with the burial mound consuming the most resources. Finally, the ciudadela is complete with the closure of the south walls.

Unlimited resources schedule

The schedule representing the soonest practical completion of the ciudadela assumes unlimited resources available on an as-needed basis. Based on the *most likely* durations, and a five-day, 40-hour workweek, the estimated completion time is 61 calendar months (Figure 3-41). In general, the average peak labor requirements range from between 200 and 280 workers, with a peak of 400. The requirement to call upon and release large numbers of workers on a daily basis makes this schedule theoretically possible, but not necessarily practical. A barchart containing the complete listing of all activities in the schedule is in Appendix G.

Task specialization vs. work party schedules

In its simplest form, the *task specialization* model assumes each group of workers is responsible for a given task or tasks, such as making and transporting adobes, with a separate group responsible for erecting a wall. In the work party model, each group is responsible for the completed product and must perform all of the tasks required. In this case, a specific work party is responsible for a completed wall, and must manufacture, transport, and erect the adobes. The resulting logic shows how the task specialization model allows scheduling activities in parallel, while the work party activities tend to occur serially (Figure 3-42). This type of logic applies to all construction activities within the massive perimeter walls.

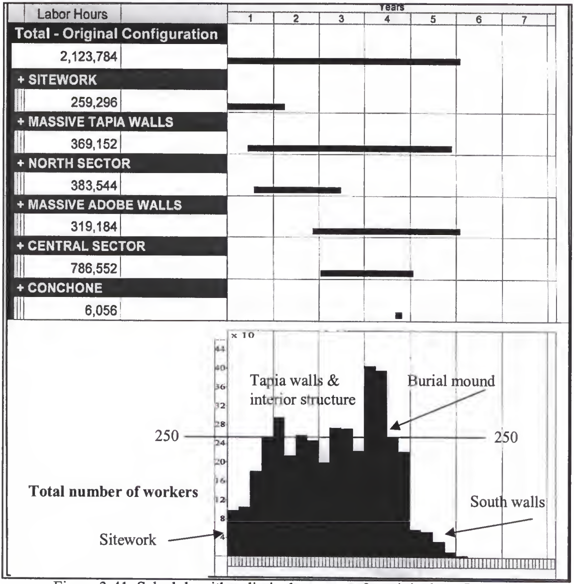


Figure 3-41: Schedule with unlimited resources for original configuration.

The schedule for constructing the massive tapia walls is the same for both labor theories. The work of mixing the tapia, transporting it to the mason, and putting it in place is essentially one operation with a series of steps, all performed simultaneously. It is not practical to divide the work between groups, and the work is equally suited for either the task specialization or work party models.

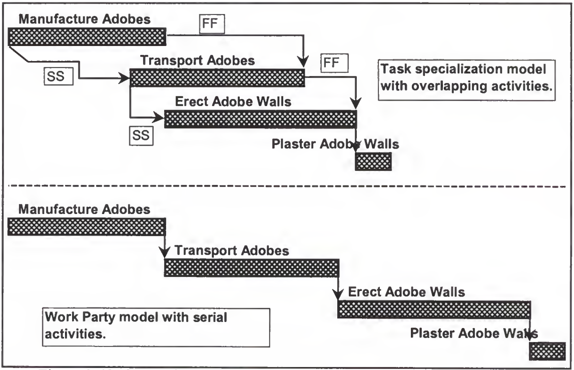


Figure 3-42: Comparison of logic between task specialization and work parties.

The schedule representing the task specialization model uses the same logic as the unlimited resource schedule. However, limiting the overall number of workers and utilizing float tends to smooth the major peaks in labor to allow for a more balanced workforce. This case results in extending the work on the burial mound over a longer period. Based on the *most likely* durations, and a five-day, 40-hour workweek, the estimated completion time is 67 calendar months (Figure 3-43). In general, the average peak labor requirements range from between 200 and 280 workers.

The work party model uses the same logic as the unlimited resource schedule for the massive walls. However, the activities for the interior of the compound are scheduled serially to represent the actions of the work party. In this case, the result extends the work in the north and central sectors over a longer period, which correspondingly extends the project duration. Based on the *most likely* durations, and a five-day, 40-hour workweek, the estimated completion time is 73 calendar months (Figure 3-44). In general, the average peak labor requirements range from between 200 and 250 workers. A comparison of the three schedules is shown in Figure 3-45.

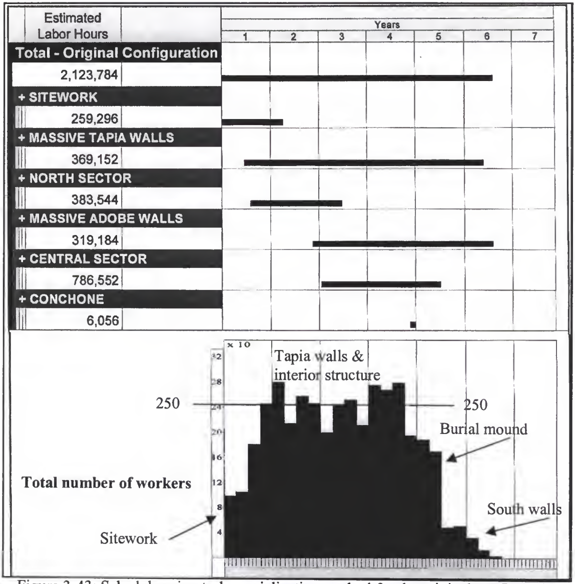


Figure 3-43: Schedule using task specialization method for the original configuration.

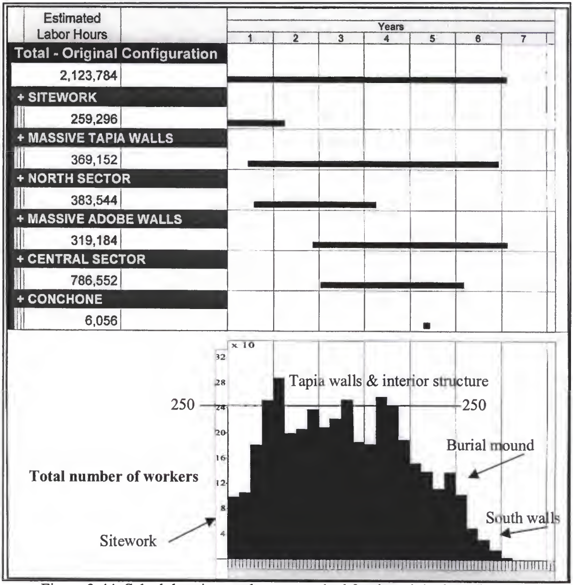


Figure 3-44: Schedule using work party method for the original configuration.

Probabilistic testing

Using the full range of *optimistic*, *pessimistic*, and *most likely* durations, each of the three scheduling scenarios was tested using the Monte Carlo techniques described earlier. The unlimited resource, task specialization, and work party models all indicated only a 30 % probability of finishing within the deterministically derived end date calculated from the *most likely* durations. Using the 95% probability range, the length of each project is 64, 70, and 77 months respectively (Figures 3-46, 3-47, & 3-48). Figure 3-49 shows the comparison of the three labor distributions. Note, the total amount of labor does not change only their distribution over time.

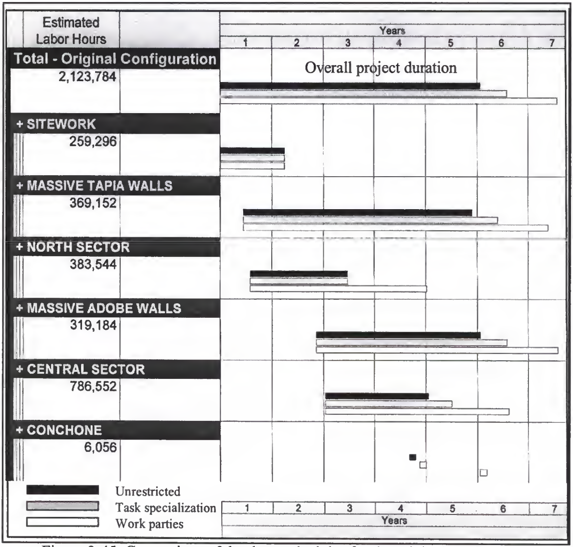


Figure 3-45: Comparison of the three schedules for the original configuration.

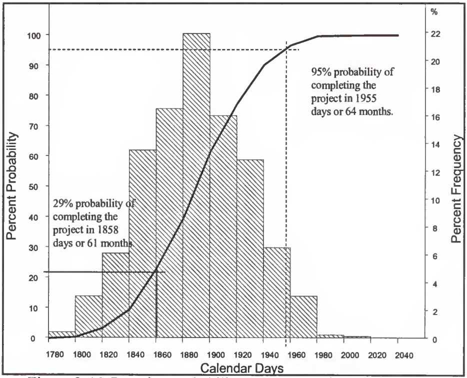


Figure 3-46: Duration probability graph for unlimited resources.

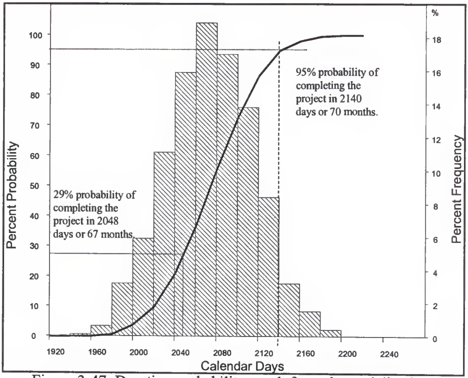


Figure 3-47: Duration probability graph for task specialization.

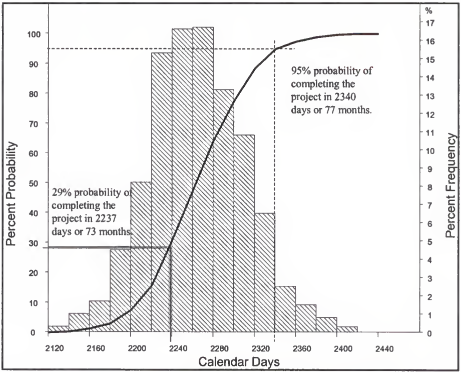


Figure 3-48: Duration probability graph for work parties.

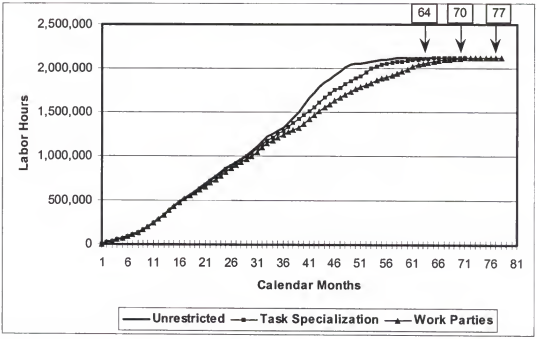


Figure 3-49: Comparison of labor distributions for the original configuration using the 95% probability project duration.

Adobe Wall Addition

Construction work plan and schedule

The construction plan to build the massive adobe perimeter walls uses the same approach as the massive tapia walls. The north, east, and west adobe walls are constructed simultaneously using corner leads at each corner, and rack-back leads in the center of the east and west wall (Figure 3-40). The physical size and space of the wall limits the number of people working on each section. Construction involves building in teams consisting of two crews of masons with five workers per crew. Two teams start at each corner and rack-back lead, and work outward. In this plan, the demolition of the north tapia wall and remodeling of the north entrance take place near the end of the project, although the work can take place any time before closing the new north adobe wall without having an impact on the overall schedule.

Comparing work parties with task specialists is impractical since simply rotating work parties to overlap with one another accomplishes the same result as the task specialization method. Developing a schedule in the serial fashion required to model the work party approach demands determining the size and number of work parties, and the amount of work performed by each, which is too speculative.

The work of building these massive adobe walls is routine, repetitive, and generally linear in nature. Consequently, scheduling the project and optimizing the labor distribution is straightforward. Using a level labor force of 150 workers and based on the *most likely* durations, with a five-day, 40-hour workweek, the estimated completion time is 31 calendar months (Figure 3-50). A barchart containing the complete listing of all activities in the schedule is in Appendix H.

Evaluating uncertainty in the schedule yields a 95% probability of completing the project in only 27 months (Figure 3-51). This is attributable to the fact that the *most likely* durations for adobe making were conservatively calculated closer to the pessimistic value insuring an initially conservative schedule with the possibility of improvement.

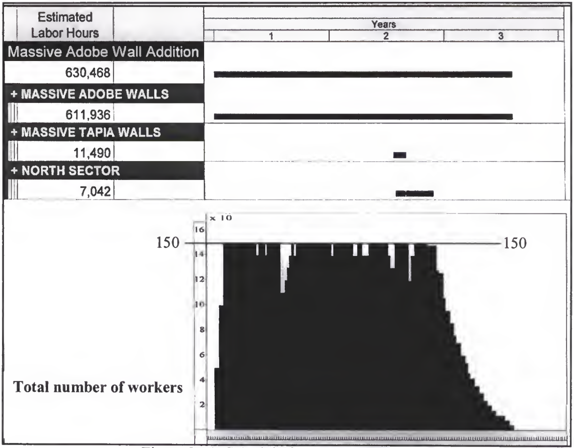


Figure 3-50: Schedule for adobe wall addition.

Discussion and Conclusions

Estimate & Schedule

The total labor investment in the original configuration of Ciudadela Rivero is roughly 2.1 million hours, with another 630,000 hours invested in the massive adobe wall addition. These estimates are accurate to the extent the actual productivity was within the ranges reflected in the unit rates.

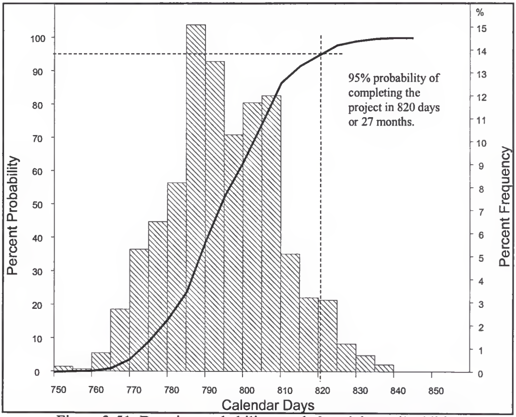


Figure 3-51: Duration probability graph for adobe wall addition.

A workforce of roughly 250 persons could have constructed Ciudadela Rivero in 5.5 to 6.5 years, based on a five-day, 40-hour workweek. For purposes of discussion, six years is the average construction time. This assumes the project was worked on continuously in a diligent and relatively efficient manner. Throughout the development of the estimates and schedules, this research opted for the conservative choice. These estimates and schedules represent practical and achievable objectives under normal circumstances and are the baseline for comparisons to other structures and labor organization strategies.

It is possible that the construction time could take less than six years. Workers performing repetitive tasks over time generally experience an increase in productivity. The time to perform a task decreases with repetition as workers learn the process and routine of their tasks. The effects of this learning curve can be significant, resulting in improvements of 30% or more in some cases (Oglesby et al. 1989: 138). However, there is no allowance in the estimates or schedules that attempts to quantify the effects of the learning curve on this project. Crashing the schedule by using labor in excess of what is normally necessary can shorten the construction time to a certain extent, but it is limited by the number of people who can effectively work in a given area. Over-staffing the project to shorten the construction time is inefficient and reduces overall productivity causing the labor cost to rise.

Conversely, it is possible to lengthen the project duration to virtually any timeframe by understaffing, working on a seasonal basis, or any other intermittent work strategy. Although technically possible, there was no attempt to simulate these scenarios.

Labor Organization

Adobe construction is a straightforward process that emphasizes quantity over quality, strength over skill. Although the approach taken here breaks the work into specific types of tasks, none of the tasks involves using skilled labor. While some tasks may be specialized, such as cana roofing, workers are essentially interchangeable throughout the project.

In this context, there is nothing to exclude either the task specialization and differentiation, or the work party organization from consideration. Task specialization and differentiation is most efficient when multiple groups of workers perform their tasks so construction activities proceed in parallel. In this case, each group is dependent upon other groups to perform their tasks in a timely manner. Consequently, coordination of the construction is required between groups requiring high level supervision. On the other hand, groups can complete activities in advance, such as adobe making that creates some flexibility in scheduling. Task specialization also tends to exhibit productivity improvements due to the learning curve.

Work parties responsible for all activities to produce a specified quantity of work, tend to create serial construction· sequences that generally extend the length of the schedule. Construction coordination stays within the group. However, work parties composed of large kin-based groups such as villages or moieties can achieve the same task differentiation and learning curve effects as the task specialization model.

One physical indicator of the use of work parties is segmented construction. Assigning a work party a specified unit of physical work tends to create noticeable breaks and joints in the construction that are not the result of normal construction practices. There is no conclusive evidence of segmented construction at Ciudadela Rivero. All horizontal and vertical joints observed in the walls are consistent with the expected techniques. Vertical cana poles in the tapia and adobe walls are not necessarily indicators of segmented construction as previously suggested (Moseley 1975b: 40) since they serve the specific purpose of maintaining alignment of the wall. Additionally, adobes at Chan Chan have no makers' marks in the adobes that provide additional evidence of segmentation as at other sites in the Moche Valley.

Under a mit'a labor tax system, large groups of people, such as a village, were responsible to the state for periodically providing a certain amount of labor for communal infrastructure. The lack of evidence of segmentation or makers' marks at Chan Chan, does not imply that a mit'a labor tax was not in place, only that the physical evidence for work parties producing a measured quantity of work is absent. Perhaps that tax took a different form than a measured output of work, such as an obligation of time rather than physical output, or the output was measured at a scale much larger than individual bricks or elements of the structure. If Chan Chan was divided into two or more moieties, and ciudadelas built in pairs (discussion to follow), then it is possible that the measured unit of work was the entire ciudadela itself.

Tapia Walls

Ciudadela Rivero is the only compound to integrate massive tapia walls into its design and the only compound to have two massive perimeter walls. The tapia walls enclosed the compound in its original configuration, followed later by the massive adobe walls (Figure 3-1). Theories concerning the function of the massive perimeter walls range from privacy (Moseley 1975: 224), to protection (Keatinge & Day 1973: 282), to expressions of power in their conspicuous consumption of labor (Conklin 1990: 63).

While the tapia walls were built first, there is a pattern of adding redundant adobe walls throughout the compound. The massive adobe wall addition, built at a significant cost, encloses east, west, and north sides of the compound. The primary objective of the addition was to duplicate the tapia walls since remodeling the entrance could have been accomplished much quicker and easier by simply reconfiguring the north tapia wall. In the central sector and conchone, the west and south interior adobe walls are also redundant (Figure 3-18). Finally, the east perimeter wall of the burial complex is made of adobe and built directly against the previously built tapia wall with no gaps.

Construction related reasons for building with tapia would include innovation, lack of available labor, and speed of construction. By the time the Chimu built Ciudadela Rivero, they had a building tradition several centuries old that changed little from beginning to end. Their architecture was standardized and exhibited little innovation in either design or techniques.

Building a tapia wall is faster and requires 40%-50% less labor than an adobe wall of similar size. By using tapia, the builders were able to complete the initial compound more quickly and with fewer workers than adobe walls. The choice was more likely to involve the desire for rapid construction time rather than a shortage of labor since the amount of labor necessary in either case was modest. It is possible that the need for speed was the motivating factor in choosing tapia for the initial perimeter walls, perhaps resulting from the unexpected death of a ruler.

With respect to the adobe wall addition, there is no engineering or construction reason for duplicating the massive tapia walls with adobe walls. The technique is not difficult and the results speak for themselves. The tapia walls performed as well or better than the massive adobe walls in the ensuing centuries of wear. If the reason was defense, it seems fair to assume that there was a perceived threat, and if that was the case adding a second exterior wall of tapia would have been a better choice due to its lower cost and speed of construction.

The explanation offered here for the redundant adobe walls is that adobe was simply seen as a more desirable building material than tapia. While both materials appear essentially the same, adobe may have had some socially grounded intrinsic value or meaning superior to tapia. Initially, the priority was to build the compound as quickly as possible. Once accomplished, the ciudadela was later *upgraded* with the addition of the massive adobe walls.

Split Inheritance

The split inheritance or one king/one compound theory posits that while earlier compounds were occupied for several generations, the latter compounds, were built sequentially and occupied by successive rulers (T. Topic 1982: 282; Moseley 1982: 15; Kolata 1990: 133). Conrad explicitly stated the theory:

> The major compounds of Chan Chan were the palaces of the kings of Chimor. Each ruler built one such structure to house himself, be the seat of government, and serve as the center for the management of his wealth. In accordance with a law of split inheritance the palace passed to the king's corporation of secondary heirs after his death. His principal heir became the next king of Chimor and built a new palace. (Conrad 1982: 108)

To satisfy this theory, the construction of the new palace would be rapid to the point in being achievable in a timeframe well within the lifetime of a king. Since the ciudadela is the seat of power and administration, it is in the best interest of a new king to build and occupy the new ciudadela as rapidly as possible.

The estimated six-year construction time for Ciudadela Rivero easily fits within the normal lifetime of a ruler. However, Ciudadela Rivero is the smallest of all the compounds, so to satisfy the time requirements of the 1 king/1 compound theory, the estimated construction time of each of the compounds must be within a lifetime.

The largest of the compounds, Laberinto, Velarde, and Gran Chimu (Figure 1-2), are up to 2.5 times larger in area than Rivero. Since the layouts of the compounds are similar with nearly the same proportion of built versus open spaces, extrapolating the labor cost of Rivero based on area gives a rough estimate of the labor investment of the other compounds. However, the massive walls surrounding Rivero are made of tapia, which are half the labor cost of adobe (Tables 3-9 & 3-10). Therefore, the estimate for Rivero must be adjusted to reflect the added cost of massive adobe walls rather than tapia. Doubling the labor hours of the tapia walls achieves this and yields an estimate of approximately 2.5 million labor hours. A comparison of the estimated labor hours between Rivero and Gran Chimu, the largest compound, would be more or less linear; meaning that Gran Chimu required over 6 million labor hours (Table 3-11).

Similarly, the added labor constructing walls of adobe instead of tapia extends the schedule by just over one year, since tapia construction is faster than adobe. The major factor controlling the construction time of a compound is space, measured by the number of workers that could work in an area at any given time. The number of workers that could physically work on the perimeter walls and interior structures limited the size and numbers of crews assigned to build Rivero. The much larger size of Gran Chimu allows many more workers to build simultaneously. If Gran Chimu is approximately 2.5 times as large as Rivero, then a conservative estimate of the average number of workers able to work is 500 or twice that of Rivero. At that level of staffing, the estimated construction time for Gran Chimu is approximately nine years (Table 3-11).

Table 3-11: Estimated labor requirements and construction time of Gran Chimu.

Compound	Area relative to Rivero	Estimated labor hours	Number of workers	Estimated construction time (in years)
Rivero*	1.0	2,500,000	250	7.1
Gran Chimu	2.5	6,250,000	500	8.9
*Rivero estimates adjusted to include adobe rather than tapia walls.				

Providing the necessary labor was available, the evidence strongly suggests that, in terms of construction time, building a new compound for each new king was achievable.

Dual Rule

Dual and quadripartite organization of society finds architectural expression throughout the Andes (Rostworowski 1990: 457; Netherly 1990: 463; Netherly & Dillehay: 1986: 86). At Chan Chan, the theory of dual rule suggests that rather than sequentially, the last four ciudadelas were built concurrently as pairs (Cavallaro 1988, Moseley 1990: 11, Netherly 1990: 483). That, "rapid construction of the last four ciudadelas is compatible with the rise and formulation of quadripartition" (Moseley 1990: 24).

The last four compounds built were Velarde, Bandelier, Tschudi, and Rivero (Kolata 1990; 129). Table 3-12 lists the compounds and their relative areas compared to Rivero. The approximate labor hours for the three other compounds are factored as shown earlier based upon the relative areas compared to the adjusted estimate for Rivero based on adobe walls. Similarly, a conservative estimate of the number of workers able to work on construction yields the estimated project durations for each of the compounds.

Constructing Velarde and Bandelier as a pair requires an average workforce of approximately 600 workers in 8.3 years. While at Tschudi and Rivero 500 workers could complete the compounds in 8.5 years. The data indicates that 1100 workers could accomplish building all four compounds simultaneously in 8.5 years accounting for almost 12 million labor hours.

Table 3-12: Estimated labor requirements and construction time of four compounds.

Compound	Area relative to Rivero	Estimated labor hours	Number of workers	Estimated construction time (in years)
Rivero*	1.0	2,500,000	250	7.1
*Rivero estimates adjusted to include adobe rather than tapia walls.				
Velarde	1.4	3,500,000	300	8.3
Bandelier	1.3	3,250,000	300	7.7
Totals for both		6,750,000	600	8.3
Tschudi	1.2	3,000,000	250	8.5
Rivero (w/tapia)	1.0	2,124,000	250	6.0
Totals for both		5,124,000	500	8.5
Total for 4 compounds		11,874,000	1100	8.5

While building the last four compounds simultaneously requires more than a four-fold increase in labor over constructing Ciudadela Rivero alone, it is still within reasonable limits given the local population. In terms of labor requirements and construction times, these data suggest that dual or quadripartitioning was feasible.

Conclusions

While substantial in size and scale, the labor requirements of 250 workers to construct Ciudadela Rivero is quite modest, especially since an estimated 30,000 persons inhabited Chan Chan during its final phase (Topic & Moseley 1983: 157). The maximum number of workers required under the most aggressive schedule (unlimited resources) was only 400, and then for just a few months (Figure 3-40). Even doubling the average labor force to an average of 500 workers in an attempt to crash the schedule to its shortest possible duration represents a relatively minor part of the population dedicated to construction.

There does not appear to be the need to import workers from surrounding areas (Mackey & Klymyshyn 1981: 104; Mackey 1987: 127), since redirecting a small portion of the resident population to constructing a single ciudadela seems entirely feasible. Even the most aggressive building program represented by the simultaneous construction of the last four compounds does not have enough impact to cause any major shifts in the local economy.

Due to the manageable size of the workforce, it is possible that the residents of Chan Chan bore the tax levied to construct the ciudadelas while the rural population met their obligations at or near their own region. Rotating groups from within the resident population gives considerably more control and flexibility to the builders than coordinating, feeding, and housing workers from a distant community. In addition, relying upon the non-agricultural resident workers has the advantage of eliminating the seasonal availability of workers. If workers living outside of Chan Chan performed the construction, the decision to use outside labor rather than the resident population was one of choice not necessity.

One of the foundations of ancient Andean societies, the ability to mobilize large work forces to construct monumental architecture, had its beginnings on the north coast of Peru (Moseley 1975b: 40, Schwartz 1982: x). While more labor intensive efforts are evident in structures such as the Pyramids of the Sun and Moon in the Moche Valley, it is difficult to extend the concept of controlling massive workforces to the construction of the ciudadelas at Chan Chan. In light of this research, theories concerning the control of mass labor and social complexity based solely on the monumental architecture of Chan Chan need revisiting.

CHAPTER 4
CONCLUSIONS

Significance

The labor investment in ancient monumental structures is often an important factor in hypotheses concerning a society's size, organization, and complexity. Prior methods of quantifying labor expenditures were limited to simply designed structures with minimal numbers of tasks. Due to the lack of practical analytical methods, complex architecture was often described subjectively offering little quantitative value, resulting in inferences that could be misleading or wrong. This research extends the study of architectural energetics to the analysis of large-scale complex architecture with this more detailed and disciplined process. The construction industry estimating standards demonstrated here provide archaeologists with a consistent, accurate, and objective means to calculate the labor investment in structures previously too complex to be proficiently analyzed.

Additionally, this present research goes beyond the static analysis offered by quantifying labor. The application of critical path method scheduling provides researchers the means to study the data in dynamic terms not previously available. Archaeologists are now able to simulate the effects of various construction and labor organization strategies in their cultural context.

Hypothesis Testing

One of the primary goals of this research was to demonstrate the flexibility and versatility of the project management methodology to the testing of multiple hypotheses. The methodology provides an especially powerful means of generating numerous *what-if* scenarios, as shown in the previous chapter by comparing the effects of the work party and task specialization labor schemes.

Once the basic data are determined, such as material quantities, productivity rates, and activity information, it is a relatively simple matter to modify the schedule logic, adjust labor availability, effectiveness of the workforce, and other variables to accurately model any number of alternate hypotheses.

For instance, the methodology demonstrated by the case study in Chapter 3 showed that Ciudadela Rivero could have been built with approximately 250 workers in 5 1/2 years based upon a 40-hour workweek. However, another researcher may conclude that the Chimu were capable of working longer hours and wants to determine the effect this change has on the estimated completion time. In this alternate hypothesis, the question becomes *what-if* the workers performed 48 hours of productive work per week instead of 40 hours. Adjusting the schedule to accommodate this change is simple and straightforward and the results from this scenario suggest a completion time of 4 1/2 years (Figure 4-1), as compared to 5 1/2 years using a 40-hour workweek (Figure 3-43). This ability to quickly and easily generate and compare alternate scenarios is a significant capability of this methodology and should not be underestimated.

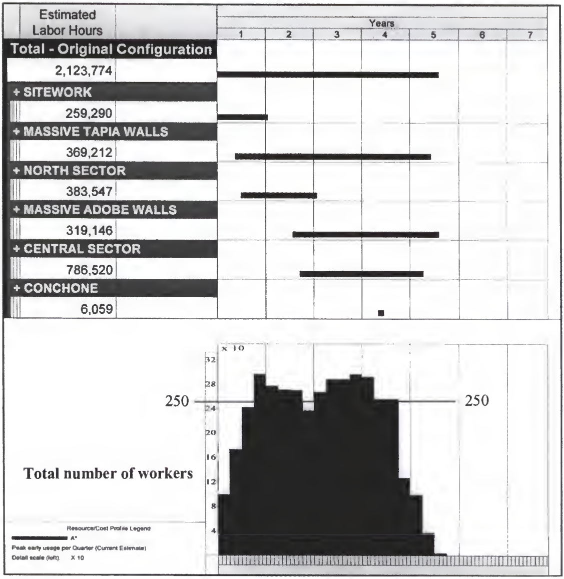


Figure 4-1: Schedule showing results of 48-hour workweek.

Conclusions

Construction project management techniques provide a systematic and reliable methodology applicable to archaeologists for quantifying ancient architecture. The benefits include:

- The methodology is portable. These procedures are not limited to Andean archaeology; they are applicable to any size project, built with any combination of materials, in any geographic region.
- The methods are reproducible. Identification and development of all data are an inherent characteristic of the process. Source data developed and used in the Ciudadela Rivero case study are reproducible by other archaeologists and construction professionals.
- The data input into the system is revisable. All data concerning productivity rates, crew sizing, and scheduling are easily revised as new information becomes available, or modified to test alternate hypotheses.
- The data are portable. Data developed for Ciudadela Rivero have direct application to the remaining ciudadelas, other Chimu architecture, and adobe architecture in general.
- Many construction operations used by the ancient builders are still in use today. A large body of contemporary construction productivity rates exist that can be directly applied to ancient techniques or used as a baseline and adjusted as necessary. These sources are a valuable supplement when there is a lack of specific experimental data.
- Weak or missing data does not hinder the modeling of construction simulations. The systematic procedures demonstrated here are especially useful in identifying areas where hard data are lacking and tend to isolate those that have a material impact on the outcome from those of little

consequence. Thus they are excellent decision making tools regarding future research and field experiments.

Applicability to Archaeological Research

The project management planning methods in this research are not limited to the analysis of architecture. The same principles and processes provide the means to plan archaeological field research.

Conducting field research is a project. It consists of a series of interrelated activities containing labor, material, budgeting, and logistics factors. The research design defines the scope of work. Subdividing the scope of work into manageable pieces permits the systematic analysis of personnel, budgeting, and logistics. Timelines resulting from critical path schedules based upon realistic work plans provide the means for planning and tracking the progress of the expedition.

Scheduling systems are the only specialized software necessary and many commercial versions are available at prices in the hundreds not thousands of dollars.

Future Research

This research introduced the concepts of critical path scheduling as an analytical tool to determine estimated construction times of ancient architecture. The three-dimensional virtual model of Ciudadela Rivero developed here represents the current generation of architectural software technology, and is rapidly becoming a fundamental tool for archaeological analyses.

Technology is quickly reaching the point where it is practical and affordable to combine data generated from project schedules with 3-D models to produce 4-D or time lapse *virtual movies*, simulating the construction of structures. The ability to literally "see" the results of the data and underlying theory opens the analytical process to non-engineering disciplines that will undoubtedly lead to new insights into ancient construction methods and labor/social organization.

The creation of these dynamic models will provide future researchers the ability to "experience" the architecture from an exciting new platform and help to elicit its deeper meaning.

APPENDIX A
WBS - ORIGINAL CONFIGURATION

WORK BREAKDOWN STRUCTURE

Original Construction

Ciudadela Rivero, Chan Chan, Peru

WBS Code	*Title*
Ciudadela Rivero: Original Configuration	
R-ST	**Sitework**
R-ST-GE	**General Excavation**
R-ST-GE-CF	Cut & Fill
R-MT	**Massive Tapia Walls**
R-MT-NW	**North Wall**
R-MT-NW-S1	Section 1
R-MT-NW-S1-L1	Level 1
R-MT-NW-S1-L2	Level 2
R-MT-NW-S1-L3	Level 3
R-MT-NW-S2	Section 2
R-MT-NW-S2-L1	Level 1
R-MT-NW-S2-L2	Level 2
R-MT-NW-S2-L3	Level 3
R-MT-EW	**East Wall**
R-MT-EW-S1	Section 1
R-MT-EW-S1-L1	Level 1
R-MT-EW-S1-L2	Level 2
R-MT-EW-S1-L3	Level 3
R-MT-EW-S2	Section 2
R-MT-EW-S2-L1	Level 1
R-MT-EW-S2-L2	Level 2
R-MT-EW-S2-L3	Level 3
R-MT-EW-S3	Section 3
R-MT-EW-S3-L1	Level 1
R-MT-EW-S3-L2	Level 2
R-MT-EW-S3-L3	Level 3
R-MT-EW-S4	Section 4
R-MT-EW-S4-L1	Level 1
R-MT-EW-S4-L2	Level 2
R-MT-EW-S4-L3	Level 3
R-MT-WW	**West Wall**
R-MT-WW-S1	Section 1
R-MT-WW-S1-L1	Level 1
R-MT-WW-S1-L2	Level 2
R-MT-WW-S1-L3	Level 3
R-MT-WW-S2	Section 2
R-MT-WW-S2-L1	Level 1
R-MT-WW-S2-L2	Level 2
R-MT-WW-S2-L3	Level 3

        - R-MT-WW-S3 Section 3
            - R-MT-WW-S3-L1 Level 1
            - R-MT-WW-S3-L2 Level 2
            - R-MT-WW-S3-L3 Level 3
        - R-MT-WW-S4 Section 4
            - R-MT-WW-S4-L1 Level 1
            - R-MT-WW-S4-L2 Level 2
            - R-MT-WW-S4-L3 Level 3
    - **R-MT-SW South Wall**
        - R-MT-SW-S1 Section 1
            - R-MT-SW-S1-L1 Level 1
            - R-MT-SW-S1-L2 Level 2
            - R-MT-SW-S1-L3 Level 3
        - R-MT-SW-S2 Section 2
            - R-MT-SW-S2-L1 Level 1
            - R-MT-SW-S2-L2 Level 2
            - R-MT-SW-S2-L3 Level 3
- **R-NS North Sector**
    - **R-NS-EC Entry Court**
        - R-NS-EC-AA Entry court
            - R-NS-EC-AA-C1 Court 1
    - **R-NS-NC Northeast Complex**
        - R-NS-NC-AA Northeast Complex
            - R-NS-NC-AA-CY Courtyard
            - R-NS-NC-AA-KC Kitchen & Courtyard
            - R-NS-NC-AA-S1 Storeroom Complex 1
    - **R-NS-WF West Forecourt & Platform**
        - R-NS-WF-AA West Forecourt & Platform
            - R-NS-WF-AA-AS Auxilliary Structures
            - R-NS-WF-AA-S3 Storeroom Complex 3
            - R-NS-WF-AA-WF West Forecourt
    - **R-NS-EA Elevated Audiencias & Storage**
        - R-NS-EA-AA Elevated Audiencias & Storage
            - R-NS-EA-AA-A1 Audiencia Court 1
            - R-NS-EA-AA-A2 Audiencia Court 2
            - R-NS-EA-AA-CY Courtyard
            - R-NS-EA-AA-EC Entry Court
            - R-NS-EA-AA-PW Perimeter Wall
            - R-NS-EA-AA-S2 Storeroom Complex 2
- **R-MA Massive Adobe Walls**
    - **R-MA-DW Central Dividing Wall**
        - R-MA-DW-AA Central Dividing Wall
        - R-MA-DW-S1 Section 1
            - R-MA-DW-S1-L1 Level 1
            - R-MA-DW-S1-L2 Level 2
            - R-MA-DW-S1-L3 Level 3

- **R-MA-WI West Interior Wall**
  - R-MA-WI-S1 Section 1
    - R-MA-WI-S1-L1 Level 1
    - R-MA-WI-S1-L2 Level 2
    - R-MA-WI-S1-L3 Level 3
  - R-MA-WI-S2 Section 2
    - R-MA-WI-S2-L1 Level 1
    - R-MA-WI-S2-L2 Level 2
    - R-MA-WI-S2-L3 Level 3
- **R-MA-SI South Interior Wall**
  - R-MA-SI-S1 Section 1
    - R-MA-SI-S1-L1 Level 1
    - R-MA-SI-S1-L2 Level 2
    - R-MA-SI-S1-L3 Level 3
  - R-MA-SI-S2 Section 2
    - R-MA-SI-S2-L1 Level 1
    - R-MA-SI-S2-L2 Level 2
    - R-MA-SI-S2-L3 Level 3

R-CS Central Sector

- **R-CS-EC Entry Court**
  - R-CS-EC-AA Entry Court
    - R-CS-EC-AA-C1 Court 1
- **R-CS-WS West Storeroom Complex**
  - R-CS-WS-AA West Storeroom Complex
    - R-CS-WS-AA-S5 Storeroom Complex 5
    - R-CS-WS-AA-S6 Storeroom Complex 6
    - R-CS-WS-AA-S7 Storeroom Complex 7
    - R-CS-WS-AA-S8 Storeroom Complex 8
- **R-CS-ES East Storage Complex**
  - R-CS-ES-AA East Storage Complex
    - R-CS-ES-AA-S4 Storeroom Complex 4
- **R-CS-AC Audiencia Court 3**
  - R-CS-AC-A3 Audiencia 3
- **R-CS-BC Burial Complex**
  - R-CS-BC-AA Burial Complex
    - R-CS-BC-AA-BM Burial Mound
    - R-CS-BC-AA-FC Forecourt
    - R-CS-BC-AA-PW Perimeter Wall
- **R-CS-SA Southern Auxilliary Structures**
  - R-CS-SA-AA Southern Auxilliary Structures
    - R-CS-SA-AA-AS Auxilliary Structures

R-CC Conchone

- **R-CC-AW Auxilliary Walls**
  - R-CC-AW-AA Auxilliary Structures
    - R-CC-AW-AA-AS Auxilliary Structures

APPENDIX B
WBS - MASSIVE ADOBE WALL ADDITION

WORK BREAKDOWN STRUCTURE

Massive Adobe Wall Addition

Ciudadela Rivero, Chan Chan, Peru

WBS Code	Title
Ciudadela Rivero - Adobe Wall Addition	
R-MT	**Massive Tapia Walls**
R-MT-NW	**North Wall**
R-MT-NW-S1	Demolition
R-NS	**North Sector**
R-NS-EC	**Entry Court**
R-NS-EC-AA	Entry court
R-NS-EC-AA-C1	Court 1
R-MA	**Massive Adobe Walls**
R-MA-NW	**North Wall**
R-MA-NW-S1	Section 1
R-MA-NW-S1-L1	Level 1
R-MA-NW-S1-L2	Level 2
R-MA-NW-S1-L3	Level 3
R-MA-NW-S2	Section 2
R-MA-NW-S2-L1	Level 1
R-MA-NW-S2-L2	Level 2
R-MA-NW-S2-L3	Level 3
R-MA-EW	**East Wall**
R-MA-EW-S1	Section 1
R-MA-EW-S1-L1	Level 1
R-MA-EW-S1-L2	Level 2
R-MA-EW-S1-L3	Level 3
R-MA-EW-S2	Section 2
R-MA-EW-S2-L1	Level 1
R-MA-EW-S2-L2	Level 2
R-MA-EW-S2-L3	Level 3
R-MA-EW-S3	Section 3
R-MA-EW-S3-L1	Level 1
R-MA-EW-S3-L2	Level 2
R-MA-EW-S3-L3	Level 3
R-MA-EW-S4	Section 4
R-MA-EW-S4-L1	Level 1
R-MA-EW-S4-L2	Level 2
R-MA-EW-S4-L3	Level 3

R-MA-WW West Wall
- R-MA-WW-S1 Section 1
  - R-MA-WW-S1-L1 Level 1
  - R-MA-WW-S1-L2 Level 2
  - R-MA-WW-S1-L3 Level 3
- R-MA-WW-S2 Section 2
  - R-MA-WW-S2-L1 Level 1
  - R-MA-WW-S2-L2 Level 2
  - R-MA-WW-S2-L3 Level 3
- R-MA-WW-S3 Section 3
  - R-MA-WW-S3-L1 Level 1
  - R-MA-WW-S3-L2 Level 2
  - R-MA-WW-S3-L3 Level 3
- R-MA-WW-S4 Section 4
  - R-MA-WW-S4-L1 Level 1
  - R-MA-WW-S4-L2 Level 2
  - R-MA-WW-S4-L3 Level 3

APPENDIX C
DETAILED ESTIMATE - ORIGINAL CONFIGURATION

Original Ciudadela Rivero - Detailed Estimate

Sitework

General Excavation

Cut & Fill

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Hand excavation-north	27,370	CM	6.00	164,220	1	100	100	206 days
Hand excavation-central	13,685	CM	6.00	82,110	1	100	100	103 days
Excavate walk-in wells-cntrl	1,080	CM	6.00	6,480	1	50	50	17 days
Excavate walk-in wells-conch	1,080	CM	6.00	6,480	1	50	50	17 days

Subtotal General Excavation 259,290 Labor Hrs.

Subtotal Sitework **259,290 Labor Hrs.**

Massive Tapia Walls

North Wall

Section 1

Level 1 0-3m

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration	
Erect tapia walls 0-3m	890	CM	10.70	9,523	5	2	10	120	days
Erect tapia walls 3-6m	640	CM	14.90	9,536	5	2	10	120	days
Erect tapia walls 6-9m	385	CM	19.20	7,392	5	2	10	93	days
Plaster walls 0-3m	540	SM	0.83	448	2	2	4	14	days
Plaster walls 3-6m	530	SM	1.25	660	2	2	4	21	days
Plaster walls 6-9m	520	SM	1.66	863	2	2	4	27	days

Subtotal Section 1 28,422 Labor Hrs.

Section 2

Level 1 0-3m

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration	
Erect tapia walls 0-3m	890	CM	10.70	9,523	5	2	10	120	days
Erect tapia walls 3-6m	640	CM	14.90	9,536	5	2	10	120	days
Erect tapia walls 6-9m	385	CM	19.20	7,392	5	2	10	93	days
Plaster walls 0-3m	540	SM	0.83	448	2	2	4	14	days
Plaster walls 3-6m	530	SM	1.25	660	2	2	4	21	days
Plaster walls 6-9m	520	SM	1.66	863	2	2	4	27	days

Subtotal Section 2 28,422 Labor Hrs.

Subtotal North Wall **56,844 Labor Hrs.**

East Wall

Section 1

Level 1 0-3m

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration	
Erect tapia walls 0-3m	985	CM	10.70	10,539	5	2	10	132	days
Erect tapia walls 3-6m	710	CM	14.90	10,579	5	2	10	133	days
Erect tapia walls 6-9m	440	CM	19.20	8,448	5	2	10	106	days
Plaster walls 0-3m	590	SM	0.83	490	2	2	4	16	days
Plaster walls 3-6m	580	SM	1.25	722	2	2	4	23	days
Plaster walls 6-9m	570	SM	1.66	946	2	2	4	30	days

Subtotal Section 1 31,724 Labor Hrs.

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Section 2								
Level 1 0-3m								
Erect tapia walls 0-3m	985	CM	10.70	10,539	5	2	10	132 days
Erect tapia walls 3-6m	710	CM	14.90	10,579	5	2	10	133 days
Erect tapia walls 6-9m	440	CM	19.20	8,448	5	2	10	106 days
Plaster walls 0-3m	590	SM	0.83	490	2	2	4	16 days
Plaster walls 3-6m	580	SM	1.25	722	2	2	4	23 days
Plaster walls 6-9m	570	SM	1.66	946	2	2	4	30 days
Subtotal Section 2				31,724 Labor Hrs.				
Section 3								
Level 1 0-3m								
Erect tapia walls 0-3m	985	CM	10.70	10,539	5	2	10	132 days
Erect tapia walls 3-6m	710	CM	14.90	10,579	5	2	10	133 days
Erect tapia walls 6-9m	440	CM	19.20	8,448	5	2	10	106 days
Plaster walls 0-3m	590	SM	0.83	490	2	2	4	16 days
Plaster walls 3-6m	580	SM	1.25	722	2	2	4	23 days
Plaster walls 6-9m	570	SM	1.66	946	2	2	4	30 days
Subtotal Section 3				31,724 Labor Hrs.				
Section 4								
Level 1 0-3m								
Erect tapia walls 0-3m	985	CM	10.70	10,539	5	2	10	132 days
Erect tapia walls 3-6m	710	CM	14.90	10,579	5	2	10	133 days
Erect tapia walls 6-9m	440	CM	19.20	8,448	5	2	10	106 days
Plaster walls 0-3m	590	SM	0.83	490	2	2	4	16 days
Plaster walls 3-6m	580	SM	1.25	722	2	2	4	23 days
Plaster walls 6-9m	570	SM	1.66	946	2	2	4	30 days
Subtotal Section 4				31,724 Labor Hrs.				
Subtotal East Wall				**126,898 Labor Hrs.**				
West Wall								
Section 1								
Level 1 0-3m								
Erect tapia walls 0-3m	990	CM	10.70	10,593	5	2	10	133 days
Erect tapia walls 3-6m	720	CM	14.90	10,728	5	2	10	135 days
Erect tapia walls 6-9m	450	CM	19.20	8,640	5	2	10	108 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
Subtotal Section 1				32,156 Labor Hrs.				

	Est. Qty	**U O M**	**Unit Rate**	**Labor Hrs.**	**Crew Size**	**No.**	**Total Workers**	**Duration Duration**
Section 2								
Level 1 0-3m								
Erect tapia walls 0-3m	990	CM	10.70	10,593	5	2	10	133 days
Erect tapia walls 3-6m	720	CM	14.90	10,728	5	2	10	135 days
Erect tapia walls 6-9m	450	CM	19.20	8,640	5	2	10	108 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
Subtotal Section 2				32,156	Labor Hrs.			
Section 3								
Level 1 0-3m								
Erect tapia walls 0-3m	990	CM	10.70	10,593	5	2	10	133 days
Erect tapia walls 3-6m	720	CM	14.90	10,728	5	2	10	135 days
Erect tapia walls 6-9m	450	CM	19.20	8,640	5	2	10	108 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
Subtotal Section 3				32,156	Labor Hrs.			
Section 4								
Level 1 0-3m								
Erect tapia walls 0-3m	990	CM	10.70	10,593	5	2	10	133 days
Erect tapia walls 3-6m	720	CM	14.90	10,728	5	2	10	135 days
Erect tapia walls 6-9m	450	CM	19.20	8,640	5	2	10	108 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
Subtotal Section 4				32,156	Labor Hrs.			
Subtotal West Wall				**128,625**	**Labor Hrs.**			

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
South Wall								
Section 1								
Level 1 0-3m								
Erect tapia walls 0-3m	890	CM	10.70	9,523	5	4	20	60 days
Erect tapia walls 3-6m	640	CM	14.90	9,536	5	4	20	60 days
Erect tapia walls 6-9m	385	CM	19.20	7,392	5	4	20	47 days
Plaster walls 0-3m	540	SM	0.83	448	2	4	8	7 days
Plaster walls 3-6m	530	SM	1.25	660	2	4	8	11 days
Plaster walls 6-9m	520	SM	1.66	863	2	4	8	14 days
Subtotal Section 1				28,422 Labor Hrs.				
Section 2								
Level 1 0-3m								
Erect tapia walls 0-3m	890	CM	10.70	9,523	5	4	20	60 days
Erect tapia walls 3-6m	640	CM	14.90	9,536	5	4	20	60 days
Erect tapia walls 6-9m	385	CM	19.20	7,392	5	4	20	47 days
Plaster walls 0-3m	540	SM	0.83	448	2	4	8	7 days
Plaster walls 3-6m	530	SM	1.25	660	2	4	8	11 days
Plaster walls 6-9m	520	SM	1.66	863	2	4	8	14 days
Subtotal Section 2				28,422 Labor Hrs.				
Subtotal South Wall				**56,844 Labor Hrs.**				

Subtotal Massive Tapia Walls **369,212 Labor Hrs.**

North Sector

Entry Court

Court 1

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	2,225	CM	7.00	15,575	5	4	20	98 days
Transport adobes	2,225	CM	7.80	17,355	1	20	20	109 days
Erect adobe walls 0-3m	248	CM	9.90	2,455	5	4	20	16 days
Erect adobe walls 3-6m	1,977	CM	13.80	27,283	5	4	20	171 days
Plaster walls 0-3m	360	SM	0.83	299	2	10	20	2 days
Plaster walls 3-6m	3,347	SM	1.25	4,167	2	10	20	27 days
Harvest algorrobo	129	LM	3.25	419	4	1	4	14 days
Fabricate roof panels	78	EA	29.80	2,324	2	2	4	73 days
Erect roof panels	78	EA	4.00	312	2	2	4	10 days

Subtotal *Entry Court* 70,189 Labor Hrs.

Northeast Complex

Kitchen & Courtyard

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	1,038	CM	7.00	7,266	5	4	20	46 days
Transport adobes	1,038	CM	7.80	8,096	1	20	20	51 days
Erect adobe walls 0-3m	1,038	CM	9.90	10,276	5	4	20	65 days
Plaster walls 0-3m	2,023	SM	0.83	1,679	2	10	20	11 days

Subtotal 27,318 Labor Hrs.

Storeroom Complex 1

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	663	CM	7.00	4,641	5	4	20	29 days
Transport adobes	663	CM	7.80	5,171	1	20	20	33 days
Erect adobe structure	313	CM	9.90	3,099	5	4	20	20 days
Erect adobe walls 3-6m	350	CM	13.80	4,830	5	4	20	31 days
Plaster walls 0-3m	868	SM	0.83	720	2	10	20	5 days
Plaster walls 3-6m	404	SM	1.25	503	2	10	20	4 days
Fabricate roof panels	26	EA	29.80	775	2	2	4	25 days
Erect roof panels	26	EA	4.00	104	2	2	4	4 days

Subtotal 19,843 Labor Hrs.

Courtyard

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	1,290	CM	7.00	9,030	5	4	20	57 days
Transport adobes	1,290	CM	7.80	10,062	1	20	20	63 days
Erect adobe walls 0-3m	1,290	CM	9.90	12,771	5	4	20	80 days
Plaster walls 0-3m	2,788	SM	0.83	2,314	2	10	20	15 days

Subtotal 34,177 Labor Hrs.

Subtotal Northeast Complex **81,338 Labor Hrs.**

	Est.	U	Unit	Labor Hrs.	Crew		Total	Duration
	Qty	**O M**	**Rate**		**Size**	**No.**	**Workers**	**Duration**
West Forecourt & Platform								
Auxiliary Structures								
Manufacture adobes	1,083	CM	7.00	7,581	5	4	20	48 days
Transport adobes	1,083	CM	7.80	8,447	1	20	20	53 days
Erect adobe walls 0-3m	340	CM	9.90	3,366	5	4	20	22 days
Erect adobe walls 3-6m	743	CM	13.80	10,253	5	4	20	65 days
Plaster walls 0-3m	836	SM	0.83	694	2	10	20	5 days
Plaster walls 3-6m	1,240	SM	1.25	1,544	2	10	20	10 days
		Subtotal		31,885	Labor Hrs.			
West Forecourt								
Manufacture adobes	1,127	CM	7.00	7,889	5	4	20	50 days
Transport adobes	1,127	CM	7.80	8,791	1	20	20	55 days
Erect adobe walls 0-3m	732	CM	9.90	7,247	5	4	20	46 days
Erect adobe walls 3-6m	395	CM	13.80	5,451	5	4	20	35 days
Plaster walls 0-3m	599	SM	0.83	497	2	10	20	4 days
Plaster walls 3-6m	753	SM	1.25	937	2	10	20	6 days
		Subtotal		30,812	Labor Hrs.			
Storeroom Complex 3								
Manufacture adobes	473	CM	7.00	3,311	5	4	20	21 days
Transport adobes	473	CM	7.80	3,689	1	20	20	24 days
Erect adobe structure	264	CM	9.90	2,614	5	4	20	17 days
Erect adobe walls 0-3m	209	CM	9.90	2,069	5	4	20	13 days
Plaster walls 0-3m	1,396	SM	0.83	1,159	2	10	20	8 days
Fabricate roof panels	24	EA	29.80	715	2	2	4	23 days
Erect roof panels	24	EA	4.00	96	2	2	4	3 days
		Subtotal		13,653	Labor Hrs.			
	Subtotal West Forecourt & Platform			**76,351**	**Labor Hrs.**			
Elevated Audiencias & Storage								
Perimeter Wall								
Manufacture adobes	1,626	CM	7.00	11,382	5	4	20	72 days
Transport adobes	1,626	CM	7.80	12,683	1	20	20	80 days
Erect adobe walls 3-6m	1,626	CM	13.80	22,439	5	4	20	141 days
Plaster walls 3-6m	1,528	SM	1.25	1,902	2	10	20	12 days
		Subtotal		48,406	Labor Hrs.			

	Est.	U	Unit	Labor Hrs.	Crew		Total	Duration
	Qty	O M	Rate		Size	No.	Workers	Duration
Storeroom Complex 2								
Manufacture adobes	1,159	CM	7.00	8,113	5	4	20	51 days
Transport adobes	1,159	CM	7.80	9,040	1	20	20	57 days
Erect adobe structure	661	CM	9.90	6,544	5	4	20	41 days
Erect adobe walls 0-3m	498	CM	9.90	4,930	5	4	20	31 days
Plaster walls 0-3m	3,393	SM	0.83	2,816	2	10	20	18 days
Fabricate roof panels	68	EA	29.80	2,026	2	2	4	64 days
Erect roof panels	68	EA	4.00	272	2	2	4	9 days
		Subtotal		33,742	Labor Hrs.			
Courtyard								
Manufacture adobes	477	CM	7.00	3,339	5	4	20	21 days
Transport adobes	477	CM	7.80	3,721	1	20	20	24 days
Erect adobe walls 0-3m	477	CM	9.90	4,722	5	4	20	30 days
Plaster walls 0-3m	903	SM	0.83	749	2	10	20	5 days
		Subtotal		12,531	Labor Hrs.			
Audiencia Court 2								
Manufacture adobes	1,271	CM	7.00	8,897	5	4	20	56 days
Transport adobes	1,271	CM	7.80	9,914	1	20	20	62 days
Erect adobe structure	190	CM	9.90	1,881	5	4	20	12 days
Erect adobe walls 0-3m	1,081	CM	9.90	10,702	5	4	20	67 days
Plaster walls 0-3m	3,424	SM	0.83	2,842	2	10	20	18 days
Harvest algorrobo	325	LM	3.25	1,056	4	1	4	33 days
Fabricate roof panels	10	EA	29.80	298	2	2	4	10 days
Erect roof panels	10	EA	4.00	40	2	2	4	2 days
		Subtotal		35,630	Labor Hrs.			
Audiencia Court 1								
Manufacture adobes	914	CM	7.00	6,398	5	4	20	40 days
Transport adobes	914	CM	7.80	7,129	1	20	20	45 days
Erect adobe structure	152	CM	9.90	1,505	5	4	20	10 days
Erect adobe walls 0-3m	762	CM	9.90	7,544	5	4	20	48 days
Plaster walls 0-3m	2,015	SM	0.83	1,672	2	10	20	11 days
Harvest algorrobo	260	LM	3.25	845	4	1	4	27 days
Fabricate roof panels	8	EA	29.80	238	2	2	4	8 days
Erect roof panels	8	EA	4.00	32	2	2	4	1 days
		Subtotal		25,364	Labor Hrs.			

Subtotal Elevated Audiencias **155,673 Labor Hrs.**

Subtotal North Sector **383,551 Labor Hrs.**

Massive Adobe Walls

Central Dividing Wall

Section 1

Level 1 0-3m

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	924	CM	7.00	6,468	5	8	40	21 days
Manufacture adobes	663	CM	7.00	4,641	5	8	40	15 days
Manufacture adobes	423	CM	7.00	2,961	5	8	40	10 days
Transport adobes	423	CM	7.80	3,299	1	40	40	11 days
Transport adobes	663	CM	7.80	5,171	1	40	40	17 days
Transport adobes	924	CM	7.80	7,207	1	40	40	23 days
Erect adobe walls 0-3m	924	CM	9.90	9,148	5	8	40	29 days
Erect adobe walls 3-6m	663	CM	13.80	9,149	5	8	40	29 days
Erect adobe walls 6-9m	423	CM	17.70	7,487	5	8	40	24 days
Plaster walls 0-3m	835	SM	0.83	693	2	8	16	6 days
Plaster walls 3-6m	830	SM	1.25	1,033	2	8	16	9 days
Plaster walls 6-9m	820	SM	1.66	1,361	2	8	16	11 days

Subtotal 58,620 Labor Hrs.

Subtotal Central Dividing Wall **58,620 Labor Hrs.**

West Interior Wall

Section 1

Level 3 6-9m

Manufacture adobes	565	CM	7.00	3,955	5	4	20	25 days
Manufacture adobes	1,250	CM	7.00	8,750	5	4	20	55 days
Manufacture adobes	910	CM	7.00	6,370	5	4	20	40 days
Transport adobes	565	CM	7.80	4,407	1	20	20	28 days
Transport adobes	910	CM	7.80	7,098	1	20	20	45 days
Transport adobes	1,250	CM	7.80	9,750	1	20	20	61 days
Erect adobe walls 0-3m	1,250	CM	9.90	12,375	5	4	20	78 days
Erect adobe walls 3-6m	910	CM	13.80	12,558	5	4	20	79 days
Erect adobe walls 6-9m	565	CM	17.70	10,001	5	4	20	63 days
Plaster walls 0-3m	745	SM	0.83	618	2	4	8	10 days
Plaster walls 3-6m	740	SM	1.25	921	2	4	8	15 days
Plaster walls 6-9m	730	SM	1.66	1,212	2	4	8	19 days

Subtotal Section 1 78,015 Labor Hrs.

Section 2

Level 2 3-6m

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration
Manufacture adobes	910	CM	7.00	6,370	5	4	20	40 days
Manufacture adobes	1,250	CM	7.00	8,750	5	4	20	55 days
Manufacture adobes	565	CM	7.00	3,955	5	4	20	25 days
Transport adobes	1,250	CM	7.80	9,750	1	20	20	61 days
Transport adobes	910	CM	7.80	7,098	1	20	20	45 days
Transport adobes	565	CM	7.80	4,407	1	20	20	28 days
Erect adobe walls 0-3m	1,250	CM	9.90	12,375	5	4	20	78 days
Erect adobe walls 3-6m	910	CM	13.80	12,558	5	4	20	79 days
Erect adobe walls 6-9m	565	CM	17.70	10,001	5	4	20	63 days
Plaster walls 0-3m	745	SM	0.83	618	2	4	8	10 days
Plaster walls 3-6m	740	SM	1.25	921	2	4	8	15 days
Plaster walls 6-9m	730	SM	1.66	1,212	2	4	8	19 days

Subtotal Section 2 78,015 Labor Hrs.

Subtotal West Interior Wall **156,030 Labor Hrs.**

South Interior Wall

Section 1

Level 2 3-6m

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration
Manufacture adobes	605	CM	7.00	4,235	5	2	10	53 days
Manufacture adobes	840	CM	7.00	5,880	5	2	10	74 days
Manufacture adobes	380	CM	7.00	2,660	5	2	10	34 days
Transport adobes	380	CM	7.80	2,964	1	10	10	38 days
Transport adobes	840	CM	7.80	6,552	1	10	10	82 days
Transport adobes	605	CM	7.80	4,719	1	10	10	59 days
Erect adobe walls 0-3m	840	CM	9.90	8,316	5	2	10	104 days
Erect adobe walls 3-6m	605	CM	13.80	8,349	5	2	10	105 days
Erect adobe walls 6-9m	380	CM	17.70	6,726	5	2	10	85 days
Plaster walls 0-3m	505	SM	0.83	419	2	2	4	14 days
Plaster walls 3-6m	495	SM	1.25	616	2	2	4	20 days
Plaster walls 6-9m	490	SM	1.66	813	2	2	4	26 days

Subtotal Section 1 52,250 Labor Hrs.

Section 2

Level 1 0-3m

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	840	CM	7.00	5,880	5	2	10	74 days
Manufacture adobes	380	CM	7.00	2,660	5	2	10	34 days
Manufacture adobes	605	CM	7.00	4,235	5	2	10	53 days
Transport adobes	380	CM	7.80	2,964	1	10	10	38 days
Transport adobes	605	CM	7.80	4,719	1	10	10	59 days
Transport adobes	840	CM	7.80	6,552	1	10	10	82 days
Erect adobe walls 0-3m	840	CM	9.90	8,316	5	2	10	104 days
Erect adobe walls 3-6m	605	CM	13.80	8,349	5	2	10	105 days
Erect adobe walls 6-9m	380	CM	17.70	6,726	5	2	10	85 days
Plaster walls 0-3m	505	SM	0.83	419	2	2	4	14 days
Plaster walls 3-6m	495	SM	1.25	616	2	2	4	20 days
Plaster walls 6-9m	490	SM	1.66	813	2	2	4	26 days

Subtotal Section 2 52,250 Labor Hrs.

***Subtotal South Interior Wall* 104,500 Labor Hrs.**

***Subtotal Massive Adobe Walls* 319,149 Labor Hrs.**

Central Sector

Entry Court

Court 1

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration	
Manufacture adobes	2,057	CM	7.00	14,399	5	4	20	90	days
Transport adobes	2,057	CM	7.80	16,045	1	20	20	101	days
Erect adobe walls 0-3m	786	CM	9.90	7,781	5	4	20	49	days
Erect adobe walls 3-6m	1,271	CM	13.80	17,540	5	4	20	110	days
Plaster walls 0-3m	753	SM	0.83	625	2	10	20	4	days
Plaster walls 3-6m	2,294	SM	1.25	2,856	2	10	20	18	days
Harvest algorrobo	71	LM	3.25	231	4	1	4	8	days
Fabricate roof panels	25	EA	29.80	745	2	2	4	24	days
Erect roof panels	25	EA	4.00	100	2	2	4	4	days
		Subtotal		60,322	Labor Hrs.				

Subtotal Entry Court **60,322 Labor Hrs.**

West Storage Complex

Storeroom Complex 5

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration	
Manufacture adobes	942	CM	7.00	6,594	5	4	20	42	days
Transport adobes	942	CM	7.80	7,348	1	20	20	46	days
Erect adobe structure	531	CM	9.90	5,257	5	4	20	33	days
Erect adobe walls 0-3m	411	CM	9.90	4,069	5	4	20	26	days
Plaster walls 0-3m	2,214	SM	0.83	1,838	2	10	20	12	days
Fabricate roof panels	20	EA	29.80	596	2	2	4	19	days
Erect roof panels	20	EA	4.00	80	2	2	4	3	days
		Subtotal		25,781	Labor Hrs.				

Storeroom Complex 6

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration	
Manufacture adobes	903	CM	7.00	6,321	5	4	20	40	days
Transport adobes	903	CM	7.80	7,043	1	20	20	45	days
Erect adobe structure	791	CM	9.90	7,831	5	4	20	49	days
Erect adobe walls 0-3m	112	CM	9.90	1,109	5	4	20	7	days
Plaster walls 0-3m	2,669	SM	0.83	2,215	2	10	20	14	days
Fabricate roof panels	28	EA	29.80	834	2	2	4	27	days
Erect roof panels	28	EA	4.00	112	2	2	4	4	days
		Subtotal		25,466	Labor Hrs.				

	Est.	U	Unit	Labor Hrs.	Crew		Total	Duration
	Qty	O M	Rate		Size	No.	Workers	Duration
Storeroom Complex 7								
Manufacture adobes	885	CM	7.00	6,195	5	4	20	39 days
Transport adobes	885	CM	7.80	6,903	1	20	20	44 days
Erect adobe structure	506	CM	9.90	5,009	5	4	20	32 days
Erect adobe walls 0-3m	379	CM	9.90	3,752	5	4	20	24 days
Plaster walls 0-3m	2,190	SM	0.83	1,818	2	10	20	12 days
Fabricate roof panels	34	EA	29.80	1,013	2	2	4	32 days
Erect roof panels	34	EA	4.00	136	2	2	4	5 days
		Subtotal		24,826	Labor Hrs.			
Storeroom Complex 8								
Manufacture adobes	1,438	CM	7.00	10,066	5	4	20	63 days
Transport adobes	1,438	CM	7.80	11,216	1	20	20	71 days
Erect adobe structure	906	CM	9.90	8,969	5	4	20	57 days
Erect adobe walls 0-3m	532	CM	9.90	5,267	5	4	20	33 days
Plaster walls 0-3m	3,653	SM	0.83	3,032	2	10	20	19 days
Fabricate roof panels	48	EA	29.80	1,430	2	2	4	45 days
Erect roof panels	48	EA	4.00	192	2	2	4	6 days
		Subtotal		40,173	Labor Hrs.			

Subtotal West Storage Complex **116,246 Labor Hrs.**

East Storage Complex

Storeroom Complex 4								
Manufacture adobes	1,776	CM	7.00	12,432	5	4	20	78 days
Transport adobes	1,776	CM	7.80	13,853	1	20	20	87 days
Erect adobe structure	1,072	CM	9.90	10,613	5	4	20	67 days
Erect adobe walls 0-3m	704	CM	9.90	6,970	5	4	20	44 days
Plaster walls 0-3m	4,580	SM	0.83	3,801	2	10	20	24 days
Fabricate roof panels	52	EA	29.80	1,550	2	2	4	49 days
Erect roof panels	52	EA	4.00	208	2	2	4	7 days
		Subtotal		49,426	Labor Hrs.			

Subtotal East Storage Complex **49,426 Labor Hrs.**

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Audiencia Court								
Audiencia Court 3								
Manufacture adobes	510	CM	7.00	3,570	5	4	20	23 days
Transport adobes	510	CM	7.80	3,978	1	20	20	25 days
Erect adobe structure	38	CM	9.90	376	5	4	20	3 days
Erect adobe walls 0-3m	472	CM	9.90	4,673	5	4	20	30 days
Plaster walls 0-3m	1,168	SM	0.83	969	2	10	20	7 days
Harvest algorrobo	65	LM	3.25	211	4	1	4	7 days
Fabricate roof panels	2	EA	29.80	60	2	2	4	2 days
Erect roof panels	2	EA	4.00	8	2	2	4	1 days
		Subtotal		13,845	Labor Hrs.			
Subtotal	*Audiencia Court*			13,845	Labor Hrs.			
Burial Complex								
Burial Mound								
Manufacture adobes	10,847	CM	7.00	75,929	5	20	100	95 days
Transport adobes	10,847	CM	7.80	84,607	1	100	100	106 days
Erect adobe structure	10,847	CM	9.90	107,385	5	20	100	135 days
Erect tapia walls 0-3m	3,060	CM	10.70	32,742	5	20	100	41 days
Erect tapia walls 3-6m	3,060	CM	14.90	45,594	5	20	100	57 days
Erect tapia walls 6-9m	3,060	CM	19.20	58,752	5	20	100	74 days
Plaster walls 3-6m	4,161	SM	1.25	5,180	2	25	50	13 days
		Subtotal		410,189	Labor Hrs.			
Perimeter Wall								
Manufacture adobes	2,036	CM	7.00	14,252	5	4	20	90 days
Transport adobes	2,036	CM	7.80	15,881	1	20	20	100 days
Erect adobe walls 3-6m	2,036	CM	13.80	28,097	5	4	20	176 days
Plaster walls 3-6m	2,859	SM	1.25	3,559	2	10	20	23 days
		Subtotal		61,789	Labor Hrs.			
Forecourt								
Manufacture adobes	1,451	CM	7.00	10,157	5	4	20	64 days
Transport adobes	1,451	CM	7.80	11,318	1	20	20	71 days
Erect adobe walls 0-3m	275	CM	9.90	2,722	5	4	20	18 days
Erect adobe walls 3-6m	1,176	CM	13.80	16,229	5	4	20	102 days
Plaster walls 0-3m	278	SM	0.83	231	2	10	20	2 days
Plaster walls 3-6m	2,253	SM	1.25	2,805	2	10	20	18 days
		Subtotal		43,462	Labor Hrs.			
Subtotal	***Burial Complex***			**515,440**	**Labor Hrs.**			

Southern Auxiliary Walls

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Auxiliary Structures								
Manufacture adobes	1,175	CM	7.00	8,225	5	4	20	52 days
Transport adobes	1,175	CM	7.80	9,165	1	20	20	58 days
Erect adobe walls 0-3m	1,175	CM	9.90	11,632	5	4	20	73 days
Plaster walls 0-3m	2,673	SM	0.83	2,219	2	10	20	14 days

***Subtotal Southern Auxiliary Walls* 31,241 Labor Hrs.**

***Subtotal Central Sector* 786,521 Labor Hrs.**

Conchone

Auxiliary Walls

Auxiliary Structures								
Manufacture adobes	230	CM	7.00	1,610	5	4	20	11 days
Transport adobes	230	CM	7.80	1,794	1	20	20	12 days
Erect adobe walls 0-3m	230	CM	9.90	2,277	5	4	20	15 days
Plaster walls 0-3m	456	SM	0.83	378	2	10	20	3 days

***Subtotal Auxiliary Walls* 6,059 Labor Hrs.**

***Subtotal Conchone* 6,059 Labor Hrs.**

Total Original Configuration 2,123,782 Labor Hrs.

APPENDIX D
DETAILED ESTIMATE - MASSIVE ADOBE WALL ADDITION

Detailed Estimate - Adobe Wall Addition

Massive Tapia Walls

North Wall

Demolition

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Hand excavation	1,915	CM	6.00	11,490	1	50	50	29 days

Subtotal North Wall 11,490 Labor Hrs.

Subtotal Massive Tapia Walls **11,490 Labor Hrs.**

North Sector

Entry Court

Court 1

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	262	CM	7.00	1,834	5	2	10	23 days
Transport adobes	262	CM	7.80	2,044	1	10	10	26 days
Erect adobe walls 0-3m	262	CM	9.90	2,594	5	2	10	33 days
Plaster walls 0-3m	687	SM	0.83	570	2	2	4	18 days

Subtotal Entry Court 7,042 Labor Hrs.

Subtotal North Sector **7,042 Labor Hrs.**

Massive Adobe Walls

North Wall

Section 1

Level 1 0-3m

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Manufacture adobes	965	CM	7.00	6,755	5	2	10	85 days
Transport adobes	965	CM	7.80	7,527	1	10	10	95 days
Erect adobe walls 0-3m	965	CM	9.90	9,553	5	2	10	120 days
Plaster walls 0-3m	575	SM	0.83	477	2	2	4	15 days

Subtotal 24,313 Labor Hrs.

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Level 2 3-6m								
Manufacture adobes	690	CM	7.00	4,830	5	2	10	61 days
Transport adobes	690	CM	7.80	5,382	1	10	10	68 days
Erect adobe walls 3-6m	690	CM	13.80	9,522	5	2	10	120 days
Plaster walls 3-6m	565	SM	1.25	703	2	2	4	22 days
			Subtotal	20,437	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	430	CM	7.00	3,010	5	2	10	38 days
Transport adobes	430	CM	7.80	3,354	1	10	10	42 days
Erect adobe walls 6-9m	430	CM	17.70	7,611	5	2	10	96 days
Plaster walls 6-9m	560	SM	1.66	930	2	2	4	30 days
			Subtotal	14,905	Labor Hrs.			
Subtotal Section 1				59,655	Labor Hrs.			
Section 2								
Level 1 0-3m								
Manufacture adobes	965	CM	7.00	6,755	5	2	10	85 days
Transport adobes	965	CM	7.80	7,527	1	10	10	95 days
Erect adobe walls 0-3m	965	CM	9.90	9,553	5	2	10	120 days
Plaster walls 0-3m	575	SM	0.83	477	2	2	4	15 days
			Subtotal	24,313	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	690	CM	7.00	4,830	5	2	10	61 days
Transport adobes	690	CM	7.80	5,382	1	10	10	68 days
Erect adobe walls 3-6m	690	CM	13.80	9,522	5	2	10	120 days
Plaster walls 3-6m	565	SM	1.25	703	2	2	4	22 days
			Subtotal	20,437	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	430	CM	7.00	3,010	5	2	10	38 days
Transport adobes	430	CM	7.80	3,354	1	10	10	42 days
Erect adobe walls 6-9m	430	CM	17.70	7,611	5	2	10	96 days
Plaster walls 6-9m	560	SM	1.66	930	2	2	4	30 days
			Subtotal	14,905	Labor Hrs.			
Subtotal Section 2				59,655	Labor Hrs.			
Subtotal North Wall				**119,310**	**Labor Hrs.**			

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
East Wall								
Section 1								
Level 1 0-3m								
Manufacture adobes	970	CM	7.00	6,790	5	2	10	85 days
Transport adobes	970	CM	7.80	7,566	1	10	10	95 days
Erect adobe walls 0-3m	970	CM	9.90	9,603	5	2	10	121 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
		Subtotal		24,457	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	700	CM	7.00	4,900	5	2	10	62 days
Transport adobes	700	CM	7.80	5,460	1	10	10	69 days
Erect adobe walls 3-6m	700	CM	13.80	9,660	5	2	10	121 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
		Subtotal		20,755	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	440	CM	7.00	3,080	5	2	10	39 days
Transport adobes	440	CM	7.80	3,432	1	10	10	43 days
Erect adobe walls 6-9m	440	CM	17.70	7,788	5	2	10	98 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
		Subtotal		15,263	Labor Hrs.			
Subtotal Section 1				60,474	Labor Hrs.			
Section 2								
Level 1 0-3m								
Manufacture adobes	970	CM	7.00	6,790	5	2	10	85 days
Transport adobes	970	CM	7.80	7,566	1	10	10	95 days
Erect adobe walls 0-3m	970	CM	9.90	9,603	5	2	10	121 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
		Subtotal		24,457	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	700	CM	7.00	4,900	5	2	10	62 days
Transport adobes	700	CM	7.80	5,460	1	10	10	69 days
Erect adobe walls 3-6m	700	CM	13.80	9,660	5	2	10	121 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
		Subtotal		20,755	Labor Hrs.			

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Level 3 6-9m								
Manufacture adobes	440	CM	7.00	3,080	5	2	10	39 days
Transport adobes	440	CM	7.80	3,432	1	10	10	43 days
Erect adobe walls 6-9m	440	CM	17.70	7,788	5	2	10	98 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
		Subtotal		15,263	Labor Hrs.			
Subtotal Section 2				60,474	Labor Hrs.			
Section 3								
Level 1 0-3m								
Manufacture adobes	970	CM	7.00	6,790	5	2	10	85 days
Transport adobes	970	CM	7.80	7,566	1	10	10	95 days
Erect adobe walls 0-3m	970	CM	9.90	9,603	5	2	10	121 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
		Subtotal		24,457	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	700	CM	7.00	4,900	5	2	10	62 days
Transport adobes	700	CM	7.80	5,460	1	10	10	69 days
Erect adobe walls 3-6m	700	CM	13.80	9,660	5	2	10	121 days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23 days
		Subtotal		20,755	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	440	CM	7.00	3,080	5	2	10	39 days
Transport adobes	440	CM	7.80	3,432	1	10	10	43 days
Erect adobe walls 6-9m	440	CM	17.70	7,788	5	2	10	98 days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31 days
		Subtotal		15,263	Labor Hrs.			
Subtotal Section 3				60,474	Labor Hrs.			
Section 4								
Level 1 0-3m								
Manufacture adobes	970	CM	7.00	6,790	5	2	10	85 days
Transport adobes	970	CM	7.80	7,566	1	10	10	95 days
Erect adobe walls 0-3m	970	CM	9.90	9,603	5	2	10	121 days
Plaster walls 0-3m	600	SM	0.83	498	2	2	4	16 days
		Subtotal		24,457	Labor Hrs.			

	Est.	U	Unit	Labor Hrs.	Crew		Total	Duration	
	Qty	O M	Rate		Size	No.	Workers	Duration	
Level 2 3-6m									
Manufacture adobes	700	CM	7.00	4,900	5	2	10	62	days
Transport adobes	700	CM	7.80	5,460	1	10	10	69	days
Erect adobe walls 3-6m	700	CM	13.80	9,660	5	2	10	121	days
Plaster walls 3-6m	590	SM	1.25	735	2	2	4	23	days
Subtotal				20,755	Labor Hrs.				
Level 3 6-9m									
Manufacture adobes	440	CM	7.00	3,080	5	2	10	39	days
Transport adobes	440	CM	7.80	3,432	1	10	10	43	days
Erect adobe walls 6-9m	440	CM	17.70	7,788	5	2	10	98	days
Plaster walls 6-9m	580	SM	1.66	963	2	2	4	31	days
Subtotal				15,263	Labor Hrs.				
Subtotal Section 4				60,474	Labor Hrs.				
Subtotal East Wall				**241,897**	**Labor Hrs.**				

West Wall

Section 1

	Est. Qty	UOM	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration	
Level 1 0-3m									
Manufacture adobes	1,010	CM	7.00	7,070	5	2	10	89	days
Transport adobes	1,010	CM	7.80	7,878	1	10	10	99	days
Erect adobe walls 0-3m	1,010	CM	9.90	9,999	5	2	10	125	days
Plaster walls 0-3m	610	SM	0.83	506	2	2	4	16	days
Subtotal				25,453	Labor Hrs.				
Level 2 3-6m									
Manufacture adobes	730	CM	7.00	5,110	5	2	10	64	days
Transport adobes	730	CM	7.80	5,694	1	10	10	72	days
Erect adobe walls 3-6m	730	CM	13.80	10,074	5	2	10	126	days
Plaster walls 3-6m	600	SM	1.25	747	2	2	4	24	days
Subtotal				21,625	Labor Hrs.				
Level 3 6-9m									
Manufacture adobes	450	CM	7.00	3,150	5	2	10	40	days
Transport adobes	450	CM	7.80	3,510	1	10	10	44	days
Erect adobe walls 6-9m	450	CM	17.70	7,965	5	2	10	100	days
Plaster walls 6-9m	590	SM	1.66	979	2	2	4	31	days
Subtotal				15,604	Labor Hrs.				
Subtotal Section 1				62,683	Labor Hrs.				

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Section 2								
Level 1 0-3m								
Manufacture adobes	1,010	CM	7.00	7,070	5	2	10	89 days
Transport adobes	1,010	CM	7.80	7,878	1	10	10	99 days
Erect adobe walls 0-3m	1,010	CM	9.90	9,999	5	2	10	125 days
Plaster walls 0-3m	610	SM	0.83	506	2	2	4	16 days
		Subtotal		25,453	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	730	CM	7.00	5,110	5	2	10	64 days
Transport adobes	730	CM	7.80	5,694	1	10	10	72 days
Erect adobe walls 3-6m	730	CM	13.80	10,074	5	2	10	126 days
Plaster walls 3-6m	600	SM	1.25	747	2	2	4	24 days
		Subtotal		21,625	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	450	CM	7.00	3,150	5	2	10	40 days
Transport adobes	450	CM	7.80	3,510	1	10	10	44 days
Erect adobe walls 6-9m	450	CM	17.70	7,965	5	2	10	100 days
Plaster walls 6-9m	590	SM	1.66	979	2	2	4	31 days
		Subtotal		15,604	Labor Hrs.			
Subtotal				*Section 2*	62,683		Labor Hrs.	
Section 3								
Level 1 0-3m								
Manufacture adobes	1,010	CM	7.00	7,070	5	2	10	89 days
Transport adobes	1,010	CM	7.80	7,878	1	10	10	99 days
Erect adobe walls 0-3m	1,010	CM	9.90	9,999	5	2	10	125 days
Plaster walls 0-3m	610	SM	0.83	506	2	2	4	16 days
		Subtotal		25,453	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	730	CM	7.00	5,110	5	2	10	64 days
Transport adobes	730	CM	7.80	5,694	1	10	10	72 days
Erect adobe walls 3-6m	730	CM	13.80	10,074	5	2	10	126 days
Plaster walls 3-6m	600	SM	1.25	747	2	2	4	24 days
		Subtotal		21,625	Labor Hrs.			

	Est. Qty	U O M	Unit Rate	Labor Hrs.	Crew Size	No.	Total Workers	Duration Duration
Level 3 6-9m								
Manufacture adobes	450	CM	7.00	3,150	5	2	10	40 days
Transport adobes	450	CM	7.80	3,510	1	10	10	44 days
Erect adobe walls 6-9m	450	CM	17.70	7,965	5	2	10	100 days
Plaster walls 6-9m	590	SM	1.66	979	2	2	4	31 days
		Subtotal		15,604	Labor Hrs.			
Subtotal Section 3				62,683	Labor Hrs.			
Section 4								
Level 1 0-3m								
Manufacture adobes	1,010	CM	7.00	7,070	5	2	10	89 days
Transport adobes	1,010	CM	7.80	7,878	1	10	10	99 days
Erect adobe walls 0-3m	1,010	CM	9.90	9,999	5	2	10	125 days
Plaster walls 0-3m	610	SM	0.83	506	2	2	4	16 days
		Subtotal		25,453	Labor Hrs.			
Level 2 3-6m								
Manufacture adobes	730	CM	7.00	5,110	5	2	10	64 days
Transport adobes	730	CM	7.80	5,694	1	10	10	72 days
Erect adobe walls 3-6m	730	CM	13.80	10,074	5	2	10	126 days
Plaster walls 3-6m	600	SM	1.25	747	2	2	4	24 days
		Subtotal		21,625	Labor Hrs.			
Level 3 6-9m								
Manufacture adobes	450	CM	7.00	3,150	5	2	10	40 days
Transport adobes	450	CM	7.80	3,510	1	10	10	44 days
Erect adobe walls 6-9m	450	CM	17.70	7,965	5	2	10	100 days
Plaster walls 6-9m	590	SM	1.66	979	2	2	4	31 days
		Subtotal		15,604	Labor Hrs.			
Subtotal Section 4				62,683	Labor Hrs.			
Subtotal West Wall				**250,731**	**Labor Hrs.**			

Subtotal Massive Adobe Walls **611,938 Labor Hrs.**

Total Adobe Wall Addition 630,469 Labor Hrs.

APPENDIX E
SCHEDULE DATA - ORIGINAL CONFIGURATION

Ciudadela Rivero - Original Configuration
Activity durations and estimated labor hour ranges by activity

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Sitework						
General Excavation						
Cut & Fill						
Central Sector						
Hand excavation	84	103	125	67,057	82,110	99,901
Excavate Walk-In Wells	14	17	20	5,292	6,480	7,884
Conchone						
Excavate Walk-In Wells	14	17	20	5,292	6,480	7,884
North Sector						
Hand excavation	168	206	250	134,113	164,220	199,801
Massive Tapia Walls						
East Wall						
Section 1						
Level 1 0-3m						
Erect tapia walls 0-3m	105	132	158	8,373	10,539	12,608
Plaster walls 0-3m	11	16	19	336	490	578
Level 2 3-6m						
Erect tapia walls 3-6m	106	133	159	8,449	10,579	12,709
Plaster walls 3-6m	16	23	27	496	722	853
Level 3 6-9m						
Erect tapia walls 6-9m	85	106	127	6,776	8,448	10,120
Plaster walls 6-9m	21	30	35	655	946	1,117
Section 2						
Level 1 0-3m						
Erect tapia walls 0-3m	105	132	158	8,373	10,539	12,608
Plaster walls 0-3m	11	16	19	336	490	578
Level 2 3-6m						
Erect tapia walls 3-6m	106	133	159	8,449	10,579	12,709
Plaster walls 3-6m	16	23	27	496	722	853

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Level 3 6-9m						
Erect tapia walls 6-9m	85	106	127	6,776	8,448	10,120
Plaster walls 6-9m	21	30	35	655	946	1,117
Section 3						
Level 1 0-3m						
Erect tapia walls 0-3m	105	132	158	8,373	10,539	12,608
Plaster walls 0-3m	11	16	19	336	490	578
Level 2 3-6m						
Erect tapia walls 3-6m	106	133	159	8,449	10,579	12,709
Plaster walls 3-6m	16	23	27	496	722	853
Level 3 6-9m						
Erect tapia walls 6-9m	85	106	127	6,776	8,448	10,120
Plaster walls 6-9m	21	30	35	655	946	1,117
Section 4						
Level 1 0-3m						
Erect tapia walls 0-3m	105	132	158	8,373	10,539	12,608
Plaster walls 0-3m	11	16	19	336	490	578
Level 2 3-6m						
Erect tapia walls 3-6m	106	133	159	8,449	10,579	12,709
Plaster walls 3-6m	16	23	27	496	722	853
Level 3 6-9m						
Erect tapia walls 6-9m	85	106	127	6,776	8,448	10,120
Plaster walls 6-9m	21	30	35	655	946	1,117
North Wall						
Section 1						
Level 1 0-3m						
Erect tapia walls 0-3m	95	120	143	7,565	9,523	11,392
Plaster walls 0-3m	10	14	17	308	448	529
Level 2 3-6m						
Erect tapia walls 3-6m	96	120	144	7,616	9,536	11,456
Plaster walls 3-6m	15	21	25	453	660	779
Level 3 6-9m						

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Erect tapia walls 6-9m	75	93	111	5,929	7,392	8,855
Plaster walls 6-9m	19	27	32	598	863	1,019
Section 2						
Level 1 0-3m						
Erect tapia walls 0-3m	95	120	143	7,565	9,523	11,392
Plaster walls 0-3m	10	14	17	308	448	529
Level 2 3-6m						
Erect tapia walls 3-6m	96	120	144	7,616	9,536	11,456
Plaster walls 3-6m	15	21	25	453	660	779
Level 3 6-9m						
Erect tapia walls 6-9m	75	93	111	5,929	7,392	8,855
Plaster walls 6-9m	19	27	32	598	863	1,019
South Wall						
Section 1						
Level 1 0-3m						
Erect tapia walls 0-3m	48	60	72	7,565	9,523	11,392
Plaster walls 0-3m	5	7	9	308	448	529
Level 2 3-6m						
Erect tapia walls 3-6m	48	60	72	7,616	9,536	11,456
Plaster walls 3-6m	8	11	13	453	660	779
Level 3 6-9m						
Erect tapia walls 6-9m	38	47	56	5,929	7,392	8,855
Plaster walls 6-9m	10	14	16	598	863	1,019
Section 2						
Level 1 0-3m						
Erect tapia walls 0-3m	48	60	72	7,565	9,523	11,392
Plaster walls 0-3m	5	7	9	308	448	529
Level 2 3-6m						
Erect tapia walls 3-6m	48	60	72	7,616	9,536	11,456
Plaster walls 3-6m	8	11	13	453	660	779
Level 3 6-9m						
Erect tapia walls 6-9m	38	47	56	5,929	7,392	8,855

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Plaster walls 6-9m	10	14	16	598	863	1,019
West Wall						
Section 1						
Level 1 0-3m						
Erect tapia walls 0-3m	106	133	159	8,415	10,593	12,672
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Erect tapia walls 3-6m	108	135	162	8,568	10,728	12,888
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Erect tapia walls 6-9m	87	108	130	6,930	8,640	10,350
Plaster walls 6-9m	21	31	36	667	963	1,137
Section 2						
Level 1 0-3m						
Erect tapia walls 0-3m	106	133	159	8,415	10,593	12,672
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Erect tapia walls 3-6m	108	135	162	8,568	10,728	12,888
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Erect tapia walls 6-9m	87	108	130	6,930	8,640	10,350
Plaster walls 6-9m	21	31	36	667	963	1,137
Section 3						
Level 1 0-3m						
Erect tapia walls 0-3m	106	133	159	8,415	10,593	12,672
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Erect tapia walls 3-6m	108	135	162	8,568	10,728	12,888
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Erect tapia walls 6-9m	87	108	130	6,930	8,640	10,350
Plaster walls 6-9m	21	31	36	667	963	1,137

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Section 4						
Level 1 0-3m						
Erect tapia walls 0-3m	106	133	159	8,415	10,593	12,672
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Erect tapia walls 3-6m	108	135	162	8,568	10,728	12,888
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Erect tapia walls 6-9m	87	108	130	6,930	8,640	10,350
Plaster walls 6-9m	21	31	36	667	963	1,137
North Sector						
Elevated Audiencias & Storage						
Audiencia Court 1						
Manufacture adobes	30	40	43	4,753	6,398	6,855
Transport adobes	39	45	52	6,124	7,129	8,226
Erect adobe structure	9	10	11	1,322	1,505	1,672
Erect adobe walls 0-3m	42	48	53	6,629	7,544	8,382
Plaster walls 0-3m	8	11	13	1,149	1,672	1,975
Harvest algorrobo	22	27	32	676	845	1,014
Fabricate roof panels	6	8	10	191	238	292
Erect roof panels	1	1	2	26	32	38
Audiencia Court 2						
Manufacture adobes	42	56	60	6,609	8,897	9,533
Transport adobes	54	62	72	8,516	9,914	11,439
Erect adobe structure	11	12	14	1,653	1,881	2,090
Erect adobe walls 0-3m	59	67	75	9,405	10,702	11,891
Plaster walls 0-3m	13	18	21	1,952	2,842	3,356
Harvest algorrobo	27	33	40	845	1,056	1,268
Fabricate roof panels	8	10	12	239	298	365
Erect roof panels	1	2	2	32	40	48
Courtyard						
Manufacture adobes	16	21	23	2,480	3,339	3,578

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Transport adobes	20	24	27	3,196	3,721	4,293
Erect adobe walls 0-3m	26	30	33	4,150	4,722	5,247
Plaster walls 0-3m	4	5	6	515	749	885
Perimeter Wall						
Manufacture adobes	53	72	77	8,455	11,382	12,195
Transport adobes	69	80	92	10,894	12,683	14,634
Erect adobe walls 3-6m	124	141	157	19,837	22,439	25,040
Plaster walls 3-6m	9	12	15	1,306	1,902	2,246
Storeroom Complex 2						
Manufacture adobes	38	51	55	6,027	8,113	8,693
Transport adobes	49	57	66	7,765	9,040	10,431
Erect adobe structure	36	41	46	5,751	6,544	7,271
Erect adobe walls 0-3m	28	31	35	4,333	4,930	5,478
Plaster walls 0-3m	13	18	21	1,934	2,816	3,325
Fabricate roof panels	51	64	78	1,625	2,026	2,482
Erect roof panels	7	9	11	218	272	326
Entry Court						
Court 1						
Manufacture adobes	73	98	105	11,570	15,575	16,688
Transport adobes	94	109	126	14,907	17,355	20,025
Erect adobe walls 0-3m	14	16	18	2,158	2,455	2,728
Erect adobe walls 3-6m	151	171	191	24,119	27,283	30,446
Plaster walls 0-3m	2	2	3	205	299	353
Plaster walls 3-6m	18	27	31	2,862	4,167	4,920
Harvest algorrobo	11	14	16	335	419	503
Fabricate roof panels	59	73	89	1,864	2,324	2,847
Erect roof panels	8	10	12	250	312	374

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Northeast Complex						
Courtyard						
Manufacture adobes	42	57	61	6,708	9,030	9,675
Transport adobes	55	63	73	8,643	10,062	11,610
Erect adobe walls 0-3m	71	80	89	11,223	12,771	14,190
Plaster walls 0-3m	10	15	18	1,589	2,314	2,732
Kitchen & Courtyard						
Manufacture adobes	34	46	49	5,398	7,266	7,785
Transport adobes	44	51	59	6,955	8,096	9,342
Erect adobe walls 0-3m	57	65	72	9,031	10,276	11,418
Plaster walls 0-3m	8	11	13	1,153	1,679	1,983
Storeroom Complex 1						
Manufacture adobes	22	29	32	3,448	4,641	4,973
Transport adobes	28	33	38	4,442	5,171	5,967
Erect adobe structure	18	20	22	2,723	3,099	3,443
Erect adobe walls 3-6m	27	31	34	4,270	4,830	5,390
Plaster walls 0-3m	4	5	6	495	720	851
Plaster walls 3-6m	3	4	4	345	503	594
Fabricate roof panels	20	25	30	621	775	949
Erect roof panels	3	4	4	83	104	125
West Forecourt & Platform						
Auxiliary Structures						
Manufacture adobes	36	48	51	5,632	7,581	8,123
Transport adobes	46	53	61	7,256	8,447	9,747
Erect adobe walls 0-3m	19	22	24	2,958	3,366	3,740
Erect adobe walls 3-6m	57	65	72	9,065	10,253	11,442
Plaster walls 0-3m	3	5	6	477	694	819
Plaster walls 3-6m	7	10	12	1,060	1,544	1,823
Storeroom Complex 3						
Manufacture adobes	16	21	23	2,460	3,311	3,548
Transport adobes	20	24	27	3,169	3,689	4,257
Erect adobe structure	15	17	19	2,297	2,614	2,904

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Erect adobe walls 0-3m	12	13	15	1,818	2,069	2,299
Plaster walls 0-3m	5	8	9	796	1,159	1,368
Fabricate roof panels	18	23	28	574	715	876
Erect roof panels	3	3	4	77	96	115
West Forecourt						
Manufacture adobes	37	50	53	5,860	7,889	8,453
Transport adobes	48	55	64	7,551	8,791	10,143
Erect adobe walls 0-3m	40	46	51	6,368	7,247	8,052
Erect adobe walls 3-6m	31	35	39	4,819	5,451	6,083
Plaster walls 0-3m	3	4	4	341	497	587
Plaster walls 3-6m	5	6	7	644	937	1,107
Massive Adobe Walls						
Central Dividing Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	16	21	22	4,805	6,468	6,930
Transport adobes	20	23	26	6,191	7,207	8,316
Erect adobe walls 0-3m	26	29	32	8,039	9,148	10,164
Plaster walls 0-3m	4	6	7	476	693	818
Level 2 3-6m						
Manufacture adobes	11	15	16	3,448	4,641	4,973
Transport adobes	14	17	19	4,442	5,171	5,967
Erect adobe walls 3-6m	26	29	32	8,089	9,149	10,210
Plaster walls 3-6m	6	9	10	710	1,033	1,220
Level 3 6-9m						
Manufacture adobes	7	10	10	2,200	2,961	3,173
Transport adobes	9	11	12	2,834	3,299	3,807
Erect adobe walls 6-9m	21	24	27	6,641	7,487	8,375
Plaster walls 6-9m	8	11	13	943	1,361	1,607

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
South Interior Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	55	74	79	4,368	5,880	6,300
Transport adobes	71	82	95	5,628	6,552	7,560
Erect adobe walls 0-3m	92	104	116	7,308	8,316	9,240
Plaster walls 0-3m	9	14	16	288	419	495
Level 2 3-6m						
Manufacture adobes	40	53	57	3,146	4,235	4,538
Transport adobes	51	59	69	4,053	4,719	5,445
Erect adobe walls 3-6m	93	105	117	7,381	8,349	9,317
Plaster walls 3-6m	14	20	23	423	616	728
Level 3 6-9m						
Manufacture adobes	25	34	36	1,976	2,660	2,850
Transport adobes	32	38	43	2,546	2,964	3,420
Erect adobe walls 6-9m	75	85	95	5,966	6,726	7,524
Plaster walls 6-9m	18	26	31	563	813	960
Section 2						
Level 1 0-3m						
Manufacture adobes	55	74	79	4,368	5,880	6,300
Transport adobes	71	82	95	5,628	6,552	7,560
Erect adobe walls 0-3m	92	104	116	7,308	8,316	9,240
Plaster walls 0-3m	9	14	16	288	419	495
Level 2 3-6m						
Manufacture adobes	40	53	57	3,146	4,235	4,538
Transport adobes	51	59	69	4,053	4,719	5,445
Erect adobe walls 3-6m	93	105	117	7,381	8,349	9,317
Plaster walls 3-6m	14	20	23	423	616	728
Level 3 6-9m						
Manufacture adobes	25	34	36	1,976	2,660	2,850
Transport adobes	32	38	43	2,546	2,964	3,420
Erect adobe walls 6-9m	75	85	95	5,966	6,726	7,524

	Activity Durations			Estimated Labor Hours		
Activity Description	OPT	ML	PESS	OPT	ML	PESS
Plaster walls 6-9m	18	26	31	563	813	960
West Interior Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	41	55	59	6,500	8,750	9,375
Transport adobes	53	61	71	8,375	9,750	11,250
Erect adobe walls 0-3m	68	78	86	10,875	12,375	13,750
Plaster walls 0-3m	7	10	12	425	618	730
Level 2 3-6m						
Manufacture adobes	30	40	43	4,732	6,370	6,825
Transport adobes	39	45	52	6,097	7,098	8,190
Erect adobe walls 3-6m	70	79	88	11,102	12,558	14,014
Plaster walls 3-6m	10	15	17	633	921	1,088
Level 3 6-9m						
Manufacture adobes	19	25	27	2,938	3,955	4,238
Transport adobes	24	28	32	3,785	4,407	5,085
Erect adobe walls 6-9m	56	63	70	8,870	10,001	11,187
Plaster walls 6-9m	14	19	23	839	1,212	1,431
Section 2						
Level 1 0-3m						
Manufacture adobes	41	55	59	6,500	8,750	9,375
Transport adobes	53	61	71	8,375	9,750	11,250
Erect adobe walls 0-3m	68	78	86	10,875	12,375	13,750
Plaster walls 0-3m	7	10	12	425	618	730
Level 2 3-6m						
Manufacture adobes	30	40	43	4,732	6,370	6,825
Transport adobes	39	45	52	6,097	7,098	8,190
Erect adobe walls 3-6m	70	79	88	11,102	12,558	14,014
Plaster walls 3-6m	10	15	17	633	921	1,088
Level 3 6-9m						
Manufacture adobes	19	25	27	2,938	3,955	4,238
Transport adobes	24	28	32	3,785	4,407	5,085

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Erect adobe walls 6-9m	56	63	70	8,870	10,001	11,187
Plaster walls 6-9m	14	19	23	839	1,212	1,431
Central Sector						
Audiencia Court						
Audiencia Court 3						
Manufacture adobes	17	23	24	2,652	3,570	3,825
Transport adobes	22	25	29	3,417	3,978	4,590
Erect adobe structure	3	3	3	331	376	418
Erect adobe walls 0-3m	26	30	33	4,106	4,673	5,192
Plaster walls 0-3m	5	7	8	666	969	1,145
Harvest algorrobo	6	7	8	169	211	254
Fabricate roof panels	2	2	3	48	60	73
Erect roof panels	1	1	1	6	8	10
Burial Complex						
Burial Mound						
Manufacture adobes	71	95	102	56,404	75,929	81,353
Transport adobes	91	106	123	72,675	84,607	97,623
Erect adobe structure	118	135	150	94,369	107,385	119,317
Erect tapia walls 0-3m	33	41	49	26,010	32,742	39,168
Erect tapia walls 3-6m	46	57	69	36,414	45,594	54,774
Erect tapia walls 6-9m	59	74	88	47,124	58,752	70,380
Plaster walls 3-6m	9	13	16	3,558	5,180	6,117
Forecourt						
Manufacture adobes	48	64	69	7,545	10,157	10,883
Transport adobes	61	71	82	9,722	11,318	13,059
Erect adobe walls 0-3m	15	18	19	2,392	2,722	3,025
Erect adobe walls 3-6m	90	102	114	14,347	16,229	18,110
Plaster walls 0-3m	1	2	2	158	231	272
Plaster walls 3-6m	13	18	21	1,926	2,805	3,312
Perimeter Wall						
Manufacture adobes	67	90	96	10,587	14,252	15,270
Transport adobes	86	100	115	13,641	15,881	18,324

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Erect adobe walls 3-6m	156	176	196	24,839	28,097	31,354
Plaster walls 3-6m	16	23	27	2,444	3,559	4,203
East Storage Complex						
Storeroom Complex 4						
Manufacture adobes	58	78	84	9,235	12,432	13,320
Transport adobes	75	87	100	11,899	13,853	15,984
Erect adobe structure	59	67	74	9,326	10,613	11,792
Erect adobe walls 0-3m	39	44	49	6,125	6,970	7,744
Plaster walls 0-3m	17	24	29	2,611	3,801	4,488
Fabricate roof panels	39	49	60	1,243	1,550	1,898
Erect roof panels	6	7	8	166	208	250
Entry Court						
Court 1						
Manufacture adobes	67	90	97	10,696	14,399	15,428
Transport adobes	87	101	116	13,782	16,045	18,513
Erect adobe walls 0-3m	43	49	55	6,838	7,781	8,646
Erect adobe walls 3-6m	97	110	123	15,506	17,540	19,573
Plaster walls 0-3m	3	4	5	429	625	738
Plaster walls 3-6m	13	18	22	1,961	2,856	3,372
Harvest algorrobo	6	8	9	185	231	277
Fabricate roof panels	19	24	29	597	745	913
Erect roof panels	3	4	4	80	100	120
Southern Auxiliary Walls						
Auxiliary Structures						
Manufacture adobes	39	52	56	6,110	8,225	8,813
Transport adobes	50	58	67	7,872	9,165	10,575
Erect adobe walls 0-3m	64	73	81	10,222	11,632	12,925
Plaster walls 0-3m	10	14	17	1,524	2,219	2,620
West Storage Complex						
Storeroom Complex 5						
Manufacture adobes	31	42	45	4,898	6,594	7,065
Transport adobes	40	46	53	6,311	7,348	8,478

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Erect adobe structure	29	33	37	4,620	5,257	5,841
Erect adobe walls 0-3m	23	26	29	3,576	4,069	4,521
Plaster walls 0-3m	8	12	14	1,262	1,838	2,170
Fabricate roof panels	15	19	23	478	596	730
Erect roof panels	2	3	3	64	80	96
Storeroom Complex 6						
Manufacture adobes	30	40	43	4,696	6,321	6,773
Transport adobes	38	45	51	6,050	7,043	8,127
Erect adobe structure	44	49	55	6,882	7,831	8,701
Erect adobe walls 0-3m	7	7	8	974	1,109	1,232
Plaster walls 0-3m	10	14	17	1,521	2,215	2,616
Fabricate roof panels	21	27	32	669	834	1,022
Erect roof panels	3	4	5	90	112	134
Storeroom Complex 7						
Manufacture adobes	29	39	42	4,602	6,195	6,638
Transport adobes	38	44	50	5,929	6,903	7,965
Erect adobe structure	28	32	35	4,402	5,009	5,566
Erect adobe walls 0-3m	21	24	27	3,297	3,752	4,169
Plaster walls 0-3m	8	12	14	1,248	1,818	2,146
Fabricate roof panels	26	32	39	813	1,013	1,241
Erect roof panels	4	5	6	109	136	163
Storeroom Complex 8						
Manufacture adobes	47	63	68	7,478	10,066	10,785
Transport adobes	61	71	81	9,635	11,216	12,942
Erect adobe structure	50	57	63	7,882	8,969	9,966
Erect adobe walls 0-3m	29	33	37	4,628	5,267	5,852
Plaster walls 0-3m	14	19	23	2,082	3,032	3,580
Fabricate roof panels	36	45	55	1,147	1,430	1,752
Erect roof panels	5	6	8	154	192	230

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Conchone						
Auxiliary Walls						
Auxiliary Structures						
Manufacture adobes	8	11	11	1,196	1,610	1,725
Transport adobes	10	12	13	1,541	1,794	2,070
Erect adobe walls 0-3m	13	15	16	2,001	2,277	2,530
Plaster walls 0-3m	2	3	3	260	378	447
Total estimated labor hour ranges				**1,739,811**	**2,123,782**	**2,441,447**

APPENDIX F
SCHEDULE DATA - MASSIVE ADOBE WALL ADDITION

Schedule Input Data: Ciudadela Rivero - Adobe Wall Addition
Activity durations and estimated labor hour ranges by activity

	Activity Durations			Estimated Labor Hours		
Activity Description	OPT	ML	PESS	OPT	ML	PESS
Massive Tapia Walls						
North Wall						
Demolition						
Hand excavation	24	29	35	9,384	11,490	13,980
North Sector						
Entry Court						
Court 1						
Manufacture adobes	18	23	25	1,362	1,834	1,965
Transport adobes	22	26	30	1,755	2,044	2,358
Erect adobe walls 0-3m	29	33	37	2,279	2,594	2,882
Plaster walls 0-3m	13	18	22	392	570	673
Massive Adobe Walls						
East Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	64	85	91	5,044	6,790	7,275
Transport adobes	82	95	110	6,499	7,566	8,730
Erect adobe walls 0-3m	106	121	134	8,439	9,603	10,670
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Manufacture adobes	46	62	66	3,640	4,900	5,250
Transport adobes	59	69	79	4,690	5,460	6,300
Erect adobe walls 3-6m	107	121	135	8,540	9,660	10,780
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Manufacture adobes	29	39	42	2,288	3,080	3,300
Transport adobes	37	43	50	2,948	3,432	3,960
Erect adobe walls 6-9m	87	98	109	6,908	7,788	8,712
Plaster walls 6-9m	21	31	36	667	963	1,137

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Section 2						
Level 1 0-3m						
Manufacture adobes	64	85	91	5,044	6,790	7,275
Transport adobes	82	95	110	6,499	7,566	8,730
Erect adobe walls 0-3m	106	121	134	8,439	9,603	10,670
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Manufacture adobes	46	62	66	3,640	4,900	5,250
Transport adobes	59	69	79	4,690	5,460	6,300
Erect adobe walls 3-6m	107	121	135	8,540	9,660	10,780
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Manufacture adobes	29	39	42	2,288	3,080	3,300
Transport adobes	37	43	50	2,948	3,432	3,960
Erect adobe walls 6-9m	87	98	109	6,908	7,788	8,712
Plaster walls 6-9m	21	31	36	667	963	1,137
Section 3						
Level 1 0-3m						
Manufacture adobes	64	85	91	5,044	6,790	7,275
Transport adobes	82	95	110	6,499	7,566	8,730
Erect adobe walls 0-3m	106	121	134	8,439	9,603	10,670
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Manufacture adobes	46	62	66	3,640	4,900	5,250
Transport adobes	59	69	79	4,690	5,460	6,300
Erect adobe walls 3-6m	107	121	135	8,540	9,660	10,780
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Manufacture adobes	29	39	42	2,288	3,080	3,300
Transport adobes	37	43	50	2,948	3,432	3,960
Erect adobe walls 6-9m	87	98	109	6,908	7,788	8,712
Plaster walls 6-9m	21	31	36	667	963	1,137

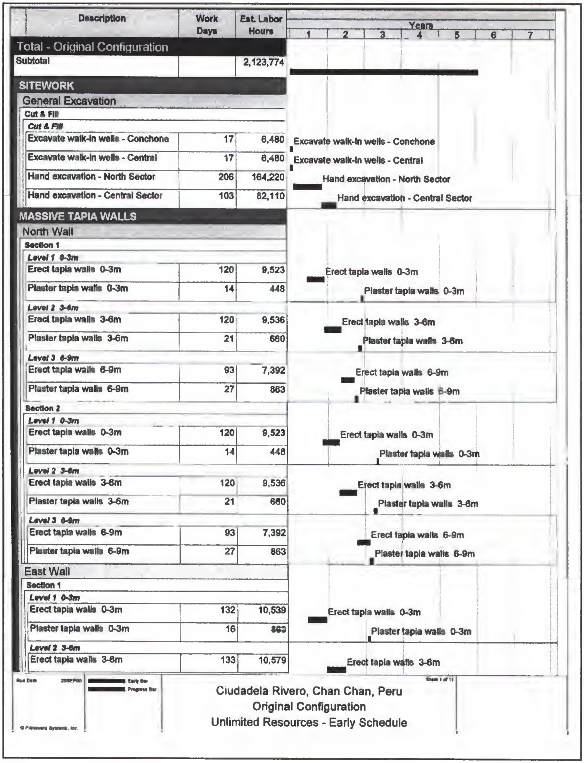
	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Section 4						
Level 1 0-3m						
Manufacture adobes	64	85	91	5,044	6,790	7,275
Transport adobes	82	95	110	6,499	7,566	8,730
Erect adobe walls 0-3m	106	121	134	8,439	9,603	10,670
Plaster walls 0-3m	11	16	19	342	498	588
Level 2 3-6m						
Manufacture adobes	46	62	66	3,640	4,900	5,250
Transport adobes	59	69	79	4,690	5,460	6,300
Erect adobe walls 3-6m	107	121	135	8,540	9,660	10,780
Plaster walls 3-6m	16	23	28	504	735	867
Level 3 6-9m						
Manufacture adobes	29	39	42	2,288	3,080	3,300
Transport adobes	37	43	50	2,948	3,432	3,960
Erect adobe walls 6-9m	87	98	109	6,908	7,788	8,712
Plaster walls 6-9m	21	31	36	667	963	1,137
North Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	63	85	91	5,018	6,755	7,238
Transport adobes	81	95	109	6,465	7,527	8,685
Erect adobe walls 0-3m	105	120	133	8,395	9,553	10,615
Plaster walls 0-3m	11	15	18	328	477	564
Level 2 3-6m						
Manufacture adobes	45	61	65	3,588	4,830	5,175
Transport adobes	58	68	78	4,623	5,382	6,210
Erect adobe walls 3-6m	106	120	133	8,418	9,522	10,626
Plaster walls 3-6m	16	22	26	483	703	831
Level 3 6-9m						
Manufacture adobes	28	38	41	2,236	3,010	3,225
Transport adobes	37	42	49	2,881	3,354	3,870
Erect adobe walls 6-9m	85	96	107	6,751	7,611	8,514

Activity Description	Activity Durations OPT	ML	PESS	Estimated Labor Hours OPT	ML	PESS
Plaster walls 6-9m	21	30	35	644	930	1,098
Section 2						
Level 1 0-3m						
Manufacture adobes	63	85	91	5,018	6,755	7,238
Transport adobes	81	95	109	6,465	7,527	8,685
Erect adobe walls 0-3m	105	120	133	8,395	9,553	10,615
Plaster walls 0-3m	11	15	18	328	477	564
Level 2 3-6m						
Manufacture adobes	45	61	65	3,588	4,830	5,175
Transport adobes	58	68	78	4,623	5,382	6,210
Erect adobe walls 3-6m	106	120	133	8,418	9,522	10,626
Plaster walls 3-6m	16	22	26	483	703	831
Level 3 6-9m						
Manufacture adobes	28	38	41	2,236	3,010	3,225
Transport adobes	37	42	49	2,881	3,354	3,870
Erect adobe walls 6-9m	85	96	107	6,751	7,611	8,514
Plaster walls 6-9m	21	30	35	644	930	1,098
West Wall						
Section 1						
Level 1 0-3m						
Manufacture adobes	66	89	95	5,252	7,070	7,575
Transport adobes	85	99	114	6,767	7,878	9,090
Erect adobe walls 0-3m	110	125	139	8,787	9,999	11,110
Plaster walls 0-3m	11	16	19	348	506	598
Level 2 3-6m						
Manufacture adobes	48	64	69	3,796	5,110	5,475
Transport adobes	62	72	83	4,891	5,694	6,570
Erect adobe walls 3-6m	112	126	141	8,906	10,074	11,242
Plaster walls 3-6m	17	24	28	513	747	882
Level 3 6-9m						
Manufacture adobes	30	40	43	2,340	3,150	3,375
Transport adobes	38	44	51	3,015	3,510	4,050

	Activity Durations			Estimated Labor Hours		
Activity Description	OPT	ML	PESS	OPT	ML	PESS
Erect adobe walls 6-9m	89	100	112	7,065	7,965	8,910
Plaster walls 6-9m	22	31	37	678	979	1,156
Section 2						
Level 1 0-3m						
Manufacture adobes	66	89	95	5,252	7,070	7,575
Transport adobes	85	99	114	6,767	7,878	9,090
Erect adobe walls 0-3m	110	125	139	8,787	9,999	11,110
Plaster walls 0-3m	11	16	19	348	506	598
Level 2 3-6m						
Manufacture adobes	48	64	69	3,796	5,110	5,475
Transport adobes	62	72	83	4,891	5,694	6,570
Erect adobe walls 3-6m	112	126	141	8,906	10,074	11,242
Plaster walls 3-6m	17	24	28	513	747	882
Level 3 6-9m						
Manufacture adobes	30	40	43	2,340	3,150	3,375
Transport adobes	38	44	51	3,015	3,510	4,050
Erect adobe walls 6-9m	89	100	112	7,065	7,965	8,910
Plaster walls 6-9m	22	31	37	678	979	1,156
Section 3						
Level 1 0-3m						
Manufacture adobes	66	89	95	5,252	7,070	7,575
Transport adobes	85	99	114	6,767	7,878	9,090
Erect adobe walls 0-3m	110	125	139	8,787	9,999	11,110
Plaster walls 0-3m	11	16	19	348	506	598
Level 2 3-6m						
Manufacture adobes	48	64	69	3,796	5,110	5,475
Transport adobes	62	72	83	4,891	5,694	6,570
Erect adobe walls 3-6m	112	126	141	8,906	10,074	11,242
Plaster walls 3-6m	17	24	28	513	747	882
Level 3 6-9m						
Manufacture adobes	30	40	43	2,340	3,150	3,375
Transport adobes	38	44	51	3,015	3,510	4,050

	Activity Durations			Estimated Labor Hours		
Activity Description	**OPT**	**ML**	**PESS**	**OPT**	**ML**	**PESS**
Erect adobe walls 6-9m	89	100	112	7,065	7,965	8,910
Plaster walls 6-9m	22	31	37	678	979	1,156
Section 4						
Level 1 0-3m						
Manufacture adobes	66	89	95	5,252	7,070	7,575
Transport adobes	85	99	114	6,767	7,878	9,090
Erect adobe walls 0-3m	110	125	139	8,787	9,999	11,110
Plaster walls 0-3m	11	16	19	348	506	598
Level 2 3-6m						
Manufacture adobes	48	64	69	3,796	5,110	5,475
Transport adobes	62	72	83	4,891	5,694	6,570
Erect adobe walls 3-6m	112	126	141	8,906	10,074	11,242
Plaster walls 3-6m	17	24	28	513	747	882
Level 3 6-9m						
Manufacture adobes	30	40	43	2,340	3,150	3,375
Transport adobes	38	44	51	3,015	3,510	4,050
Erect adobe walls 6-9m	89	100	112	7,065	7,965	8,910
Plaster walls 6-9m	22	31	37	678	979	1,156
Total estimated labor hour ranges				**526,305**	**630,469**	**705,565**

APPENDIX G
SCHEDULE OF ORIGINAL CONFIGURATION



Description	Work Days	Est. Labor Hours
Total - Original Configuration		
Subtotal		2,123,774
SITEWORK		
General Excavation		
Cut & Fill		
Cut & Fill		
Excavate walk-in wells - Conchone	17	6,480
Excavate walk-in wells - Central	17	6,480
Hand excavation - North Sector	206	164,220
Hand excavation - Central Sector	103	82,110
MASSIVE TAPIA WALLS		
North Wall		
Section 1		
Level 1 0-3m		
Erect tapia walls 0-3m	120	9,523
Plaster tapia walls 0-3m	14	448
Level 2 3-6m		
Erect tapia walls 3-6m	120	9,536
Plaster tapia walls 3-6m	21	660
Level 3 6-9m		
Erect tapia walls 6-9m	93	7,392
Plaster tapia walls 6-9m	27	863
Section 2		
Level 1 0-3m		
Erect tapia walls 0-3m	120	9,523
Plaster tapia walls 0-3m	14	448
Level 2 3-6m		
Erect tapia walls 3-6m	120	9,536
Plaster tapia walls 3-6m	21	660
Level 3 6-9m		
Erect tapia walls 6-9m	93	7,392
Plaster tapia walls 6-9m	27	863
East Wall		
Section 1		
Level 1 0-3m		
Erect tapia walls 0-3m	132	10,539
Plaster tapia walls 0-3m	16	863
Level 2 3-6m		
Erect tapia walls 3-6m	133	10,579

Run Date 20SEP00

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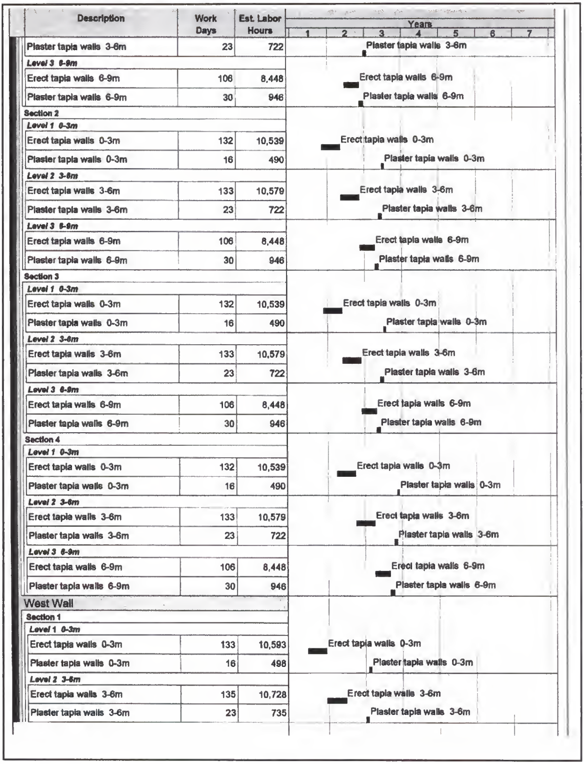
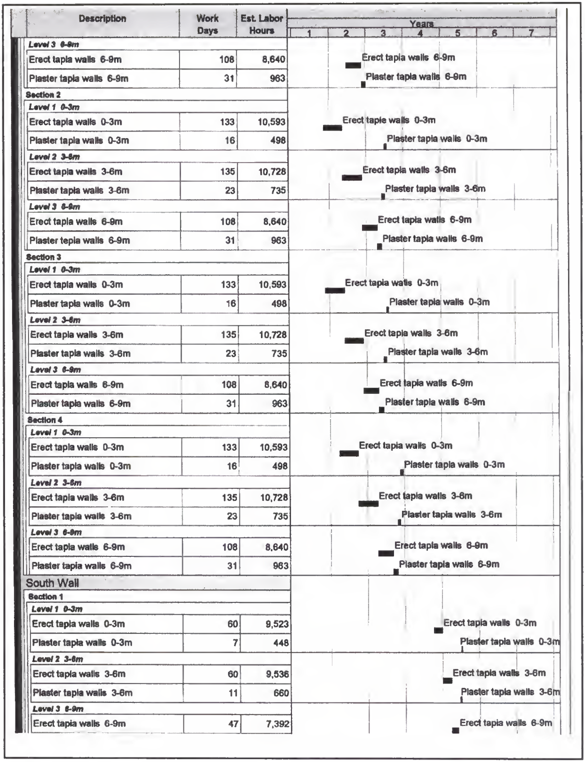
Sheet 1 of 11

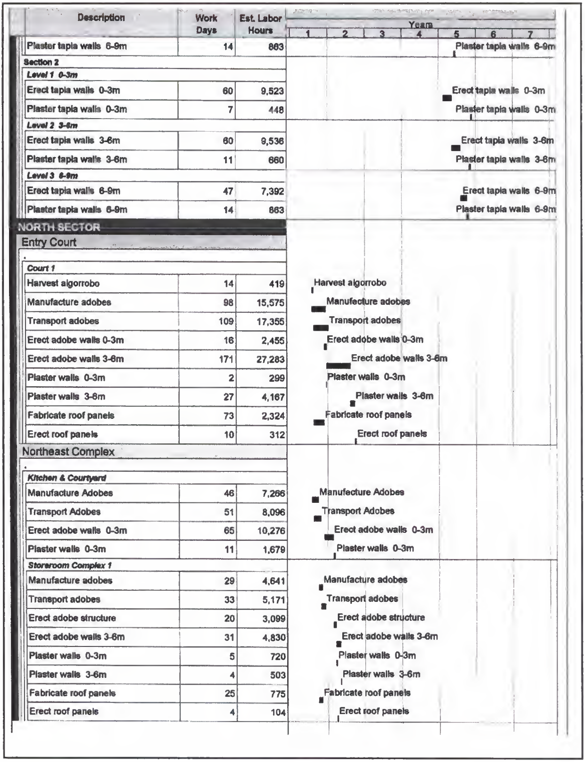
Ciudadela Rivero, Chan Chan, Peru
Original Configuration
Unlimited Resources - Early Schedule



Description	Work Days	Est. Labor Hours
Plaster tapia walls 3-6m	23	722
Level 3 6-9m		
Erect tapia walls 6-9m	106	8,448
Plaster tapia walls 6-9m	30	946
Section 2		
Level 1 0-3m		
Erect tapia walls 0-3m	132	10,539
Plaster tapia walls 0-3m	16	490
Level 2 3-6m		
Erect tapia walls 3-6m	133	10,579
Plaster tapia walls 3-6m	23	722
Level 3 6-9m		
Erect tapia walls 6-9m	106	8,448
Plaster tapia walls 6-9m	30	946
Section 3		
Level 1 0-3m		
Erect tapia walls 0-3m	132	10,539
Plaster tapia walls 0-3m	16	490
Level 2 3-6m		
Erect tapia walls 3-6m	133	10,579
Plaster tapia walls 3-6m	23	722
Level 3 6-9m		
Erect tapia walls 6-9m	106	8,448
Plaster tapia walls 6-9m	30	946
Section 4		
Level 1 0-3m		
Erect tapia walls 0-3m	132	10,539
Plaster tapia walls 0-3m	16	490
Level 2 3-6m		
Erect tapia walls 3-6m	133	10,579
Plaster tapia walls 3-6m	23	722
Level 3 6-9m		
Erect tapia walls 6-9m	106	8,448
Plaster tapia walls 6-9m	30	946
West Wall		
Section 1		
Level 1 0-3m		
Erect tapia walls 0-3m	133	10,593
Plaster tapia walls 0-3m	16	498
Level 2 3-6m		
Erect tapia walls 3-6m	135	10,728
Plaster tapia walls 3-6m	23	735

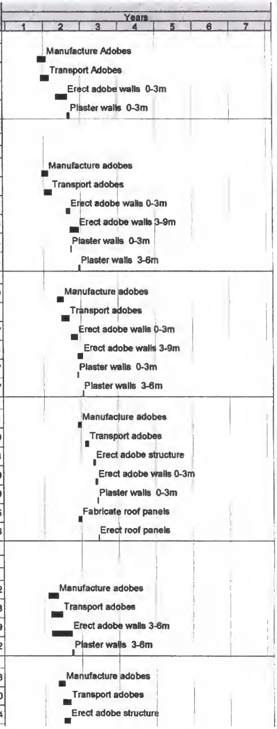


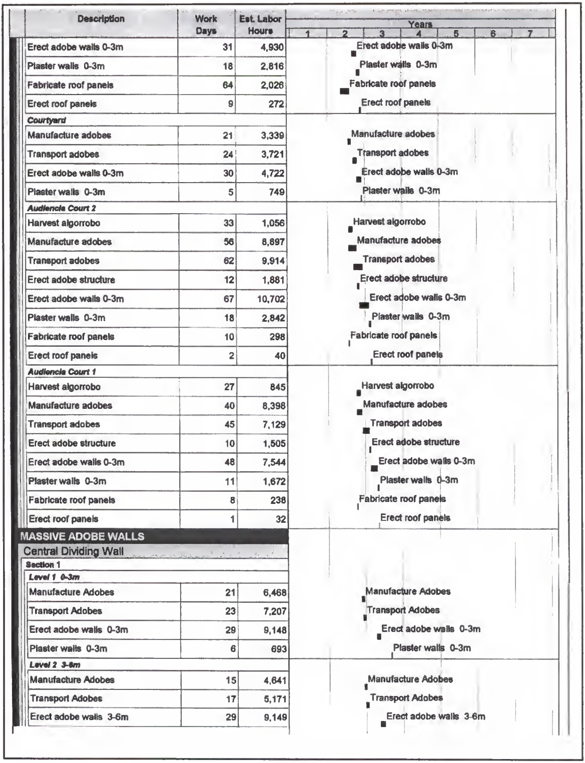
Description	Work Days	Est. Labor Hours
Level 3 6-9m		
Erect tapia walls 6-9m	108	8,640
Plaster tapia walls 6-9m	31	963
Section 2		
Level 1 0-3m		
Erect tapia walls 0-3m	133	10,593
Plaster tapia walls 0-3m	16	498
Level 2 3-6m		
Erect tapia walls 3-6m	135	10,728
Plaster tapia walls 3-6m	23	735
Level 3 6-9m		
Erect tapia walls 6-9m	108	8,640
Plaster tapia walls 6-9m	31	963
Section 3		
Level 1 0-3m		
Erect tapia walls 0-3m	133	10,593
Plaster tapia walls 0-3m	16	498
Level 2 3-6m		
Erect tapia walls 3-6m	135	10,728
Plaster tapia walls 3-6m	23	735
Level 3 6-9m		
Erect tapia walls 6-9m	108	8,640
Plaster tapia walls 6-9m	31	963
Section 4		
Level 1 0-3m		
Erect tapia walls 0-3m	133	10,593
Plaster tapia walls 0-3m	16	498
Level 2 3-6m		
Erect tapia walls 3-6m	135	10,728
Plaster tapia walls 3-6m	23	735
Level 3 6-9m		
Erect tapia walls 6-9m	108	8,640
Plaster tapia walls 6-9m	31	963
South Wall		
Section 1		
Level 1 0-3m		
Erect tapia walls 0-3m	60	9,523
Plaster tapia walls 0-3m	7	448
Level 2 3-6m		
Erect tapia walls 3-6m	60	9,536
Plaster tapia walls 3-6m	11	660
Level 3 6-9m		
Erect tapia walls 6-9m	47	7,392



Description	Work Days	Est. Labor Hours
Plaster tapia walls 6-9m	14	863
Section 2		
Level 1 0-3m		
Erect tapia walls 0-3m	60	9,523
Plaster tapia walls 0-3m	7	448
Level 2 3-6m		
Erect tapia walls 3-6m	60	9,536
Plaster tapia walls 3-6m	11	660
Level 3 6-9m		
Erect tapia walls 6-9m	47	7,392
Plaster tapia walls 6-9m	14	863
NORTH SECTOR		
Entry Court		
Court 1		
Harvest algorrobo	14	419
Manufacture adobes	98	15,575
Transport adobes	109	17,355
Erect adobe walls 0-3m	16	2,455
Erect adobe walls 3-6m	171	27,283
Plaster walls 0-3m	2	299
Plaster walls 3-6m	27	4,167
Fabricate roof panels	73	2,324
Erect roof panels	10	312
Northeast Complex		
Kitchen & Courtyard		
Manufacture Adobes	46	7,266
Transport Adobes	51	8,096
Erect adobe walls 0-3m	65	10,276
Plaster walls 0-3m	11	1,679
Storeroom Complex 1		
Manufacture adobes	29	4,641
Transport adobes	33	5,171
Erect adobe structure	20	3,099
Erect adobe walls 3-6m	31	4,830
Plaster walls 0-3m	5	720
Plaster walls 3-6m	4	503
Fabricate roof panels	25	775
Erect roof panels	4	104

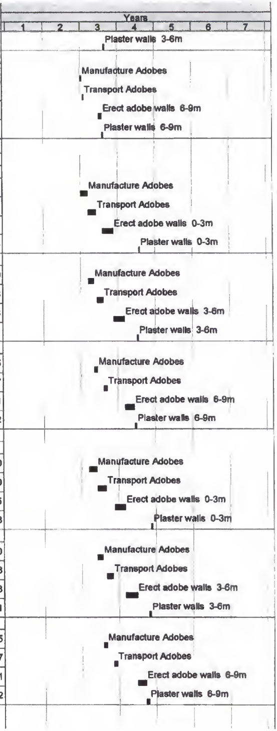
Description	Work Days	Est. Labor Hours
Courtyard		
Manufacture Adobes	57	9,030
Transport Adobes	63	10,062
Erect adobe walls 0-3m	80	12,771
Plaster walls 0-3m	15	2,314
West Forecourt & Platform		
.		
Auxiliary Structures		
Manufacture adobes	48	7,581
Transport adobes	53	8,447
Erect adobe walls 0-3m	22	3,366
Erect adobe walls 3-9m	65	10,253
Plaster walls 0-3m	5	694
Plaster walls 3-6m	10	1,544
West Forecourt		
Manufacture adobes	50	7,889
Transport adobes	55	8,791
Erect adobe walls 0-3m	46	7,247
Erect adobe walls 3-9m	35	5,451
Plaster walls 0-3m	4	497
Plaster walls 3-6m	6	937
Storeroom Complex 3		
Manufacture adobes	21	3,311
Transport adobes	24	3,689
Erect adobe structure	17	2,614
Erect adobe walls 0-3m	13	2,069
Plaster walls 0-3m	8	1,159
Fabricate roof panels	23	715
Erect roof panels	3	96
Elevated Audiencias & Storage		
.		
Perimeter Wall		
Manufacture adobes	72	11,382
Transport adobes	80	12,683
Erect adobe walls 3-6m	141	22,439
Plaster walls 3-6m	12	1,902
Storeroom Complex 2		
Manufacture adobes	51	8,113
Transport adobes	57	9,040
Erect adobe structure	41	6,544



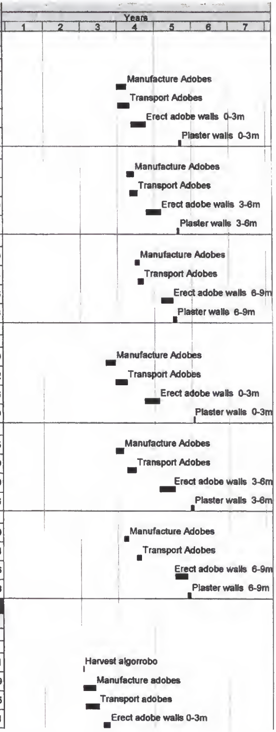


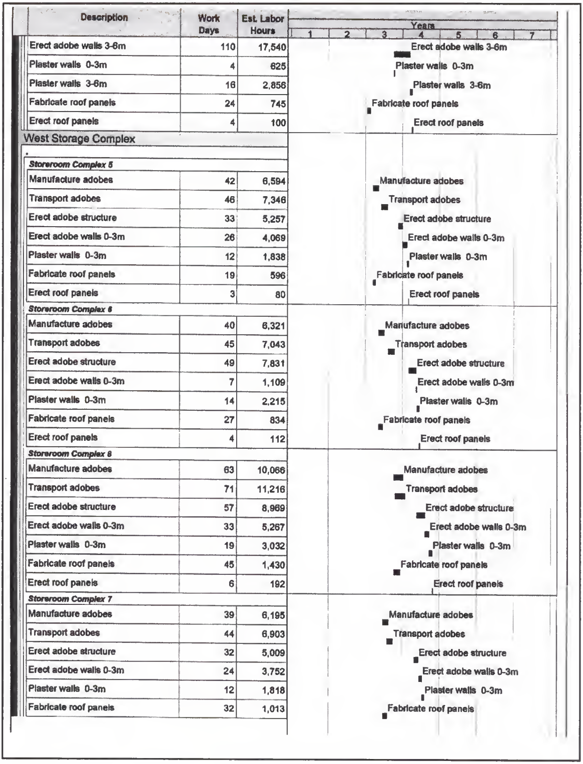
Description	Work Days	Est. Labor Hours
Erect adobe walls 0-3m	31	4,930
Plaster walls 0-3m	18	2,816
Fabricate roof panels	64	2,026
Erect roof panels	9	272
Courtyard		
Manufacture adobes	21	3,339
Transport adobes	24	3,721
Erect adobe walls 0-3m	30	4,722
Plaster walls 0-3m	5	749
Audiencia Court 2		
Harvest algorrobo	33	1,056
Manufacture adobes	56	8,897
Transport adobes	62	9,914
Erect adobe structure	12	1,881
Erect adobe walls 0-3m	67	10,702
Plaster walls 0-3m	18	2,842
Fabricate roof panels	10	298
Erect roof panels	2	40
Audiencia Court 1		
Harvest algorrobo	27	845
Manufacture adobes	40	8,398
Transport adobes	45	7,129
Erect adobe structure	10	1,505
Erect adobe walls 0-3m	48	7,544
Plaster walls 0-3m	11	1,672
Fabricate roof panels	8	238
Erect roof panels	1	32
MASSIVE ADOBE WALLS		
Central Dividing Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	21	6,468
Transport Adobes	23	7,207
Erect adobe walls 0-3m	29	9,148
Plaster walls 0-3m	6	693
Level 2 3-6m		
Manufacture Adobes	15	4,641
Transport Adobes	17	5,171
Erect adobe walls 3-6m	29	9,149

Description	Work Days	Est. Labor Hours
Plaster walls 3-6m	9	1,033
Level 3 6-9m		
Manufacture Adobes	10	2,961
Transport Adobes	11	3,299
Erect adobe walls 6-9m	24	7,487
Plaster walls 6-9m	11	1,361
West Interior Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	55	8,750
Transport Adobes	61	9,750
Erect adobe walls 0-3m	78	12,375
Plaster walls 0-3m	10	618
Level 2 3-6m		
Manufacture Adobes	40	6,370
Transport Adobes	45	7,098
Erect adobe walls 3-6m	79	12,558
Plaster walls 3-6m	15	921
Level 3 6-9m		
Manufacture Adobes	25	3,955
Transport Adobes	28	4,407
Erect adobe walls 6-9m	63	10,001
Plaster walls 6-9m	19	1,212
Section 2		
Level 1 0-3m		
Manufacture Adobes	55	8,750
Transport Adobes	61	9,750
Erect adobe walls 0-3m	78	12,375
Plaster walls 0-3m	10	618
Level 2 3-6m		
Manufacture Adobes	40	6,370
Transport Adobes	45	7,098
Erect adobe walls 3-6m	79	12,558
Plaster walls 3-6m	15	921
Level 3 6-9m		
Manufacture Adobes	25	3,955
Transport Adobes	28	4,407
Erect adobe walls 6-9m	63	10,001
Plaster walls 6-9m	19	1,212

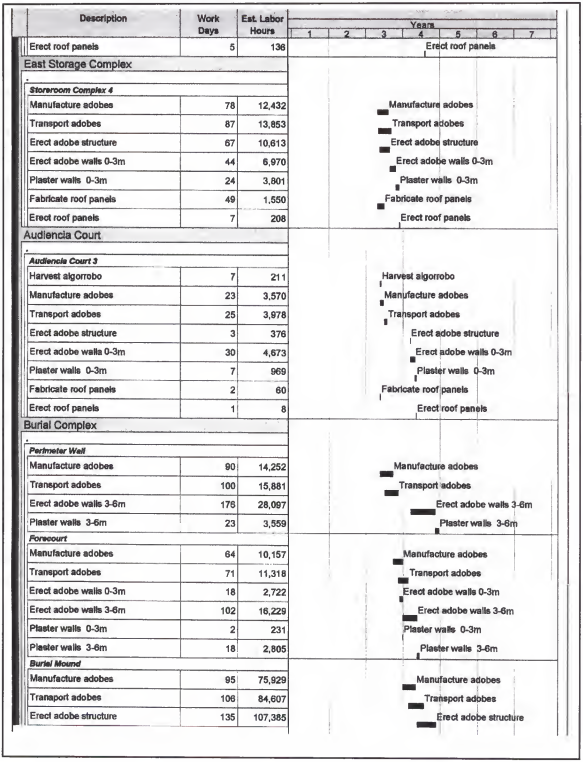


Description	Work Days	Est. Labor Hours
South Interior Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	74	5,880
Transport Adobes	82	6,552
Erect adobe walls 0-3m	104	8,316
Plaster walls 0-3m	14	419
Level 2 3-6m		
Manufacture Adobes	53	4,235
Transport Adobes	59	4,719
Erect adobe walls 3-6m	105	8,349
Plaster walls 3-6m	20	616
Level 3 6-9m		
Manufacture Adobes	34	2,660
Transport Adobes	38	2,964
Erect adobe walls 6-9m	85	6,726
Plaster walls 6-9m	26	813
Section 2		
Level 1 0-3m		
Manufacture Adobes	74	5,880
Transport Adobes	82	6,552
Erect adobe walls 0-3m	104	8,316
Plaster walls 0-3m	14	419
Level 2 3-6m		
Manufacture Adobes	53	4,235
Transport Adobes	59	4,719
Erect adobe walls 3-6m	105	8,349
Plaster walls 3-6m	20	616
Level 3 6-9m		
Manufacture Adobes	34	2,660
Transport Adobes	38	2,964
Erect adobe walls 6-9m	85	6,726
Plaster walls 6-9m	26	813
CENTRAL SECTOR		
Entry Court		
Court 1		
Harvest algorrobo	8	231
Manufacture adobes	90	14,399
Transport adobes	101	16,045
Erect adobe walls 0-3m	49	7,781

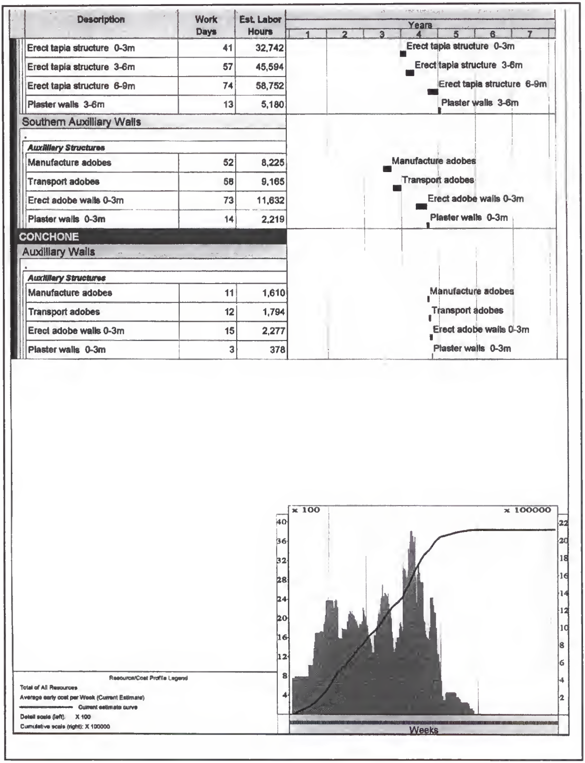




Description	Work Days	Est. Labor Hours
Erect adobe walls 3-6m	110	17,540
Plaster walls 0-3m	4	625
Plaster walls 3-6m	16	2,856
Fabricate roof panels	24	745
Erect roof panels	4	100
West Storage Complex		
Storeroom Complex 5		
Manufacture adobes	42	6,594
Transport adobes	46	7,346
Erect adobe structure	33	5,257
Erect adobe walls 0-3m	26	4,069
Plaster walls 0-3m	12	1,838
Fabricate roof panels	19	596
Erect roof panels	3	80
Storeroom Complex 6		
Manufacture adobes	40	6,321
Transport adobes	45	7,043
Erect adobe structure	49	7,831
Erect adobe walls 0-3m	7	1,109
Plaster walls 0-3m	14	2,215
Fabricate roof panels	27	834
Erect roof panels	4	112
Storeroom Complex 8		
Manufacture adobes	63	10,066
Transport adobes	71	11,216
Erect adobe structure	57	8,969
Erect adobe walls 0-3m	33	5,267
Plaster walls 0-3m	19	3,032
Fabricate roof panels	45	1,430
Erect roof panels	6	192
Storeroom Complex 7		
Manufacture adobes	39	6,195
Transport adobes	44	6,903
Erect adobe structure	32	5,009
Erect adobe walls 0-3m	24	3,752
Plaster walls 0-3m	12	1,818
Fabricate roof panels	32	1,013



Description	Work Days	Est. Labor Hours
Erect roof panels	5	136
East Storage Complex		
Storeroom Complex 4		
Manufacture adobes	78	12,432
Transport adobes	87	13,853
Erect adobe structure	67	10,613
Erect adobe walls 0-3m	44	6,970
Plaster walls 0-3m	24	3,801
Fabricate roof panels	49	1,550
Erect roof panels	7	208
Audiencia Court		
Audiencia Court 3		
Harvest algorrobo	7	211
Manufacture adobes	23	3,570
Transport adobes	25	3,978
Erect adobe structure	3	376
Erect adobe walls 0-3m	30	4,673
Plaster walls 0-3m	7	969
Fabricate roof panels	2	60
Erect roof panels	1	8
Burial Complex		
Perimeter Wall		
Manufacture adobes	90	14,252
Transport adobes	100	15,881
Erect adobe walls 3-6m	176	28,097
Plaster walls 3-6m	23	3,559
Forecourt		
Manufacture adobes	64	10,157
Transport adobes	71	11,318
Erect adobe walls 0-3m	18	2,722
Erect adobe walls 3-6m	102	16,229
Plaster walls 0-3m	2	231
Plaster walls 3-6m	18	2,805
Burial Mound		
Manufacture adobes	95	75,929
Transport adobes	106	84,607
Erect adobe structure	135	107,385



Description	Work Days	Est. Labor Hours
Erect tapia structure 0-3m	41	32,742
Erect tapia structure 3-6m	57	45,594
Erect tapia structure 6-9m	74	58,752
Plaster walls 3-6m	13	5,180
Southern Auxiliary Walls		
Auxiliary Structures		
Manufacture adobes	52	8,225
Transport adobes	58	9,165
Erect adobe walls 0-3m	73	11,632
Plaster walls 0-3m	14	2,219
CONCHONE		
Auxiliary Walls		
Auxiliary Structures		
Manufacture adobes	11	1,610
Transport adobes	12	1,794
Erect adobe walls 0-3m	15	2,277
Plaster walls 0-3m	3	378

Resource/Cost Profile Legend

Total of All Resources

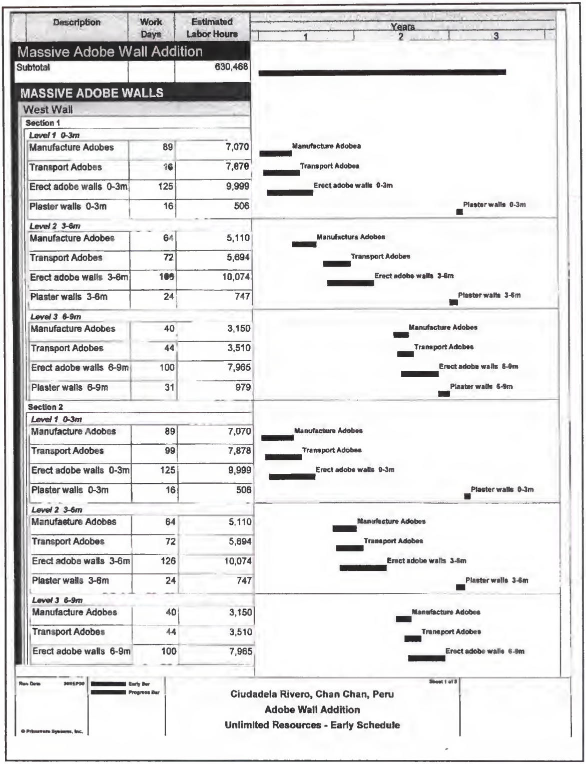
Average early cost per Week (Current Estimate)

——— Current estimate curve

Detail scale (left): X 100

Cumulative scale (right): X 100000

APPENDIX H
SCHEDULE OF ADOBE WALL ADDITION



Description	Work Days	Estimated Labor Hours
Massive Adobe Wall Addition		
Subtotal		630,468
MASSIVE ADOBE WALLS		
West Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	89	7,070
Transport Adobes	99	7,878
Erect adobe walls 0-3m	125	9,999
Plaster walls 0-3m	16	506
Level 2 3-6m		
Manufacture Adobes	64	5,110
Transport Adobes	72	5,694
Erect adobe walls 3-6m	126	10,074
Plaster walls 3-6m	24	747
Level 3 6-9m		
Manufacture Adobes	40	3,150
Transport Adobes	44	3,510
Erect adobe walls 6-9m	100	7,965
Plaster walls 6-9m	31	979
Section 2		
Level 1 0-3m		
Manufacture Adobes	89	7,070
Transport Adobes	99	7,878
Erect adobe walls 0-3m	125	9,999
Plaster walls 0-3m	16	506
Level 2 3-6m		
Manufaeture Adobes	64	5,110
Transport Adobes	72	5,694
Erect adobe walls 3-6m	126	10,074
Plaster walls 3-6m	24	747
Level 3 6-9m		
Manufacture Adobes	40	3,150
Transport Adobes	44	3,510
Erect adobe walls 6-9m	100	7,965

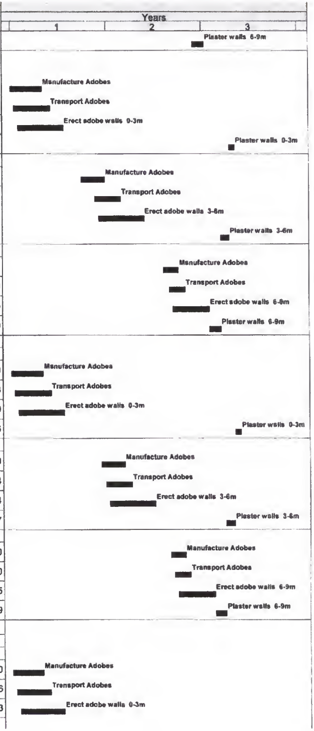
Run Date 30SEP00

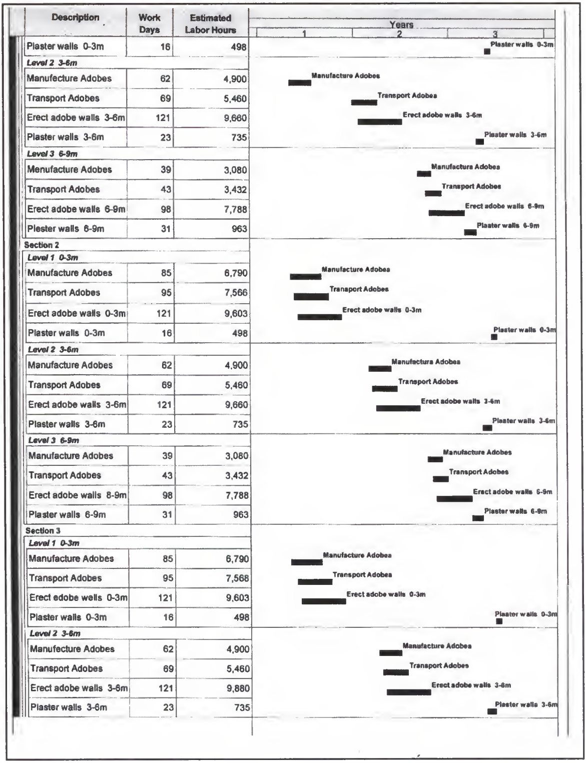
Sheet 1 of 3

Ciudadela Rivero, Chan Chan, Peru
Adobe Wall Addition
Unlimited Resources - Early Schedule

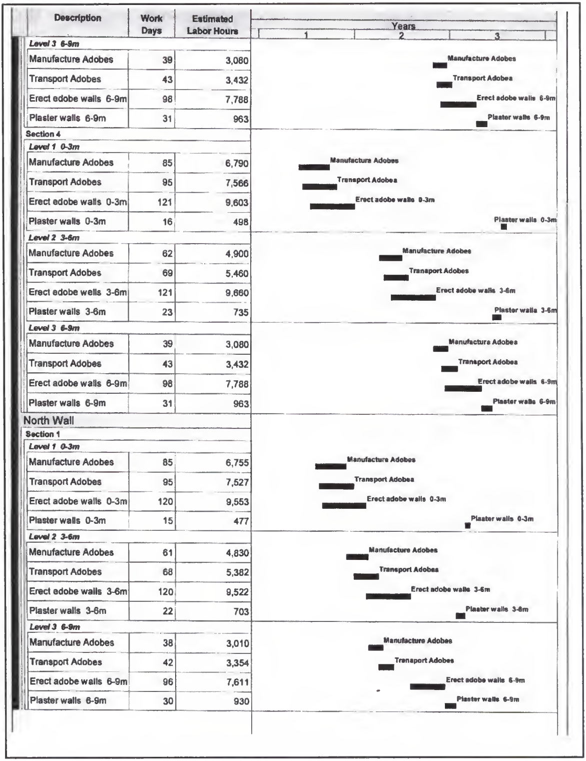
© Primavera Systems, Inc.

Description	Work Days	Estimated Labor Hours
Plaster walls 6-9m	31	979
Section 3		
Level 1 0-3m		
Manufacture Adobes	89	7,070
Transport Adobes	99	7,676
Erect adobe walls 0-3m	125	9,999
Plaster walls 0-3m	16	506
Level 2 3-6m		
Manufacture Adobes	64	5,110
Transport Adobes	72	5,694
Erect adobe walls 3-6m	126	10,074
Plaster walls 3-6m	24	747
Level 3 6-9m		
Manufacture Adobes	40	3,150
Transport Adobes	44	3,510
Erect adobe walls 6-9m	100	7,965
Plaster walls 6-9m	31	979
Section 4		
Level 1 0-3m		
Manufacture Adobes	89	7,070
Transport Adobes	99	7,678
Erect adobe walls 0-3m	125	9,999
Plaster walls 0-3m	16	506
Level 2 3-6m		
Manufacture Adobes	64	5,110
Transport Adobes	72	5,694
Erect adobe walls 3-6m	126	10,074
Plaster walls 3-6m	24	747
Level 3 6-9m		
Manufacture Adobes	40	3,150
Transport Adobes	44	3,510
Erect adobe walls 6-9m	100	7,965
Plaster walls 6-9m	31	979
East Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	65	6,790
Transport Adobes	95	7,566
Erect adobe walls 0-3m	121	9,603

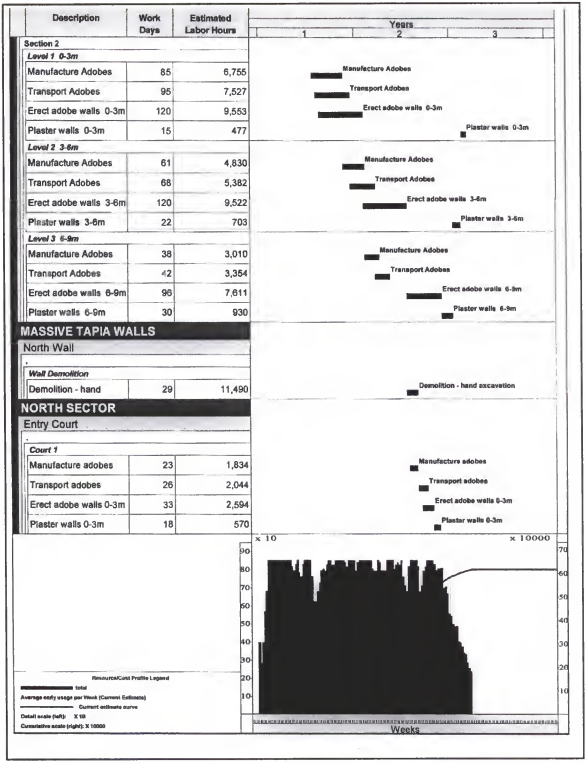




Description	Work Days	Estimated Labor Hours
Plaster walls 0-3m	16	498
Level 2 3-6m		
Manufacture Adobes	62	4,900
Transport Adobes	69	5,460
Erect adobe walls 3-6m	121	9,660
Plaster walls 3-6m	23	735
Level 3 6-9m		
Manufacture Adobes	39	3,080
Transport Adobes	43	3,432
Erect adobe walls 6-9m	98	7,788
Plaster walls 6-9m	31	963
Section 2		
Level 1 0-3m		
Manufacture Adobes	85	6,790
Transport Adobes	95	7,566
Erect adobe walls 0-3m	121	9,603
Plaster walls 0-3m	16	498
Level 2 3-6m		
Manufacture Adobes	62	4,900
Transport Adobes	69	5,460
Erect adobe walls 3-6m	121	9,660
Plaster walls 3-6m	23	735
Level 3 6-9m		
Manufacture Adobes	39	3,080
Transport Adobes	43	3,432
Erect adobe walls 8-9m	98	7,788
Plaster walls 6-9m	31	963
Section 3		
Level 1 0-3m		
Manufacture Adobes	85	6,790
Transport Adobes	95	7,568
Erect adobe walls 0-3m	121	9,603
Plaster walls 0-3m	16	498
Level 2 3-6m		
Manufacture Adobes	62	4,900
Transport Adobes	69	5,460
Erect adobe walls 3-6m	121	9,880
Plaster walls 3-6m	23	735



Description	Work Days	Estimated Labor Hours
Level 3 6-9m		
Manufacture Adobes	39	3,080
Transport Adobes	43	3,432
Erect edobe walls 6-9m	98	7,788
Plaster walls 6-9m	31	963
Section 4		
Level 1 0-3m		
Manufacture Adobes	85	6,790
Transport Adobes	95	7,566
Erect edobe walls 0-3m	121	9,603
Plaster walls 0-3m	16	498
Level 2 3-6m		
Manufacture Adobes	62	4,900
Transport Adobes	69	5,460
Erect edobe wells 3-6m	121	9,660
Plaster walls 3-6m	23	735
Level 3 6-9m		
Manufacture Adobes	39	3,080
Transport Adobes	43	3,432
Erect adobe walls 6-9m	98	7,788
Plaster walls 6-9m	31	963
North Wall		
Section 1		
Level 1 0-3m		
Manufacture Adobes	85	6,755
Transport Adobes	95	7,527
Erect adobe walls 0-3m	120	9,553
Plaster walls 0-3m	15	477
Level 2 3-6m		
Menufacture Adobes	61	4,830
Transport Adobes	68	5,382
Erect edobe walls 3-6m	120	9,522
Plaster walls 3-6m	22	703
Level 3 6-9m		
Manufacture Adobes	38	3,010
Transport Adobes	42	3,354
Erect adobe walls 6-9m	96	7,611
Plaster walls 6-9m	30	930



Description	Work Days	Estimated Labor Hours
Section 2		
Level 1 0-3m		
Manufacture Adobes	85	6,755
Transport Adobes	95	7,527
Erect adobe walls 0-3m	120	9,553
Plaster walls 0-3m	15	477
Level 2 3-6m		
Manufacture Adobes	61	4,830
Transport Adobes	68	5,382
Erect adobe walls 3-6m	120	9,522
Plaster walls 3-6m	22	703
Level 3 6-9m		
Manufacture Adobes	38	3,010
Transport Adobes	42	3,354
Erect adobe walls 6-9m	96	7,611
Plaster walls 6-9m	30	930
MASSIVE TAPIA WALLS		
North Wall		
.		
Wall Demolition		
Demolition - hand	29	11,490
NORTH SECTOR		
Entry Court		
.		
Court 1		
Manufacture adobes	23	1,834
Transport adobes	26	2,044
Erect adobe walls 0-3m	33	2,594
Plaster walls 0-3m	18	570

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Mr. Smailes has extensive experience in project management in the fields of construction, telecommunications, and aerospace/defense since receiving his bachelor and master's degree in Building Construction from the University of Florida in 1976 and 1977 respectively.

Through his career, Mr. Smailes has performed as a cost/schedule engineer, scheduling software consultant and most recently as vice-president of a project management consulting firm. Employers and clients include J.A. Jones Construction, Bechtel Corp., the State of Alaska, AT&T, Bell South, Motorola, Boeing Aerospace, Argonne National Laboratory, the U.S. Missile Command, and Coca Cola, with direct project responsibility on projects ranging from housing developments, nuclear and fossil-fueled power plants, NASA payload management, and wireless communications for the 1996 Summer Olympics.

He has taught construction curriculums at the University of Florida as a graduate teaching assistant in 1977 and 1997, and as an instructor at Southern Polytechnic Institute.

Mr. Smailes is a Certified General Contractor in the State of Florida, and a Certified Project Management Professional by the Project Management Institute.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Brisbane H. Brown, Jr., Chair
Professor of Building Construction

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Michael Edward Moseley
Professor of Anthropology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ian Flood
Assistant Professor of Building Construction

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Design, Planning, and Construction and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 2000

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